Draft Environmental Impact Statement
Copper Flat Copper Mine
BLM/NM/ES-16-02-1793

Comments Presented by

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Submitted by US Mail to: BLM Las Cruces District Office, Copper Flat Copper Mine Project, Attention: Doug Haywood - Project Manager, 1800 Marquess Street, Las Cruces, New Mexico 88005; and by e-mail to BLM_NM_LCDO_Comments@blm.gov

TRANSMITTAL LETTER

February 29, 2016

Bureau of Land Management
Las Cruces District Office
Copper Flat Copper Mine Project
Attention: Doug Haywood - Project Manager
1800 Marquess Street
Las Cruces, New Mexico 88005

Dear Mr. Haywood,

I regret that you have failed to withdraw the Draft Environmental Impact Statement (DEIS) for the Copper Flat Copper Mine as I formally requested in my December 16, 2015 statement at the public meeting in Hillsboro on this DEIS. This DEIS, as structured, has denied me the opportunity to participate in the review of a Draft Environmental Impact Statement for the subject project. The DEIS does not provide a base case which is the proposed action plan for the project and a set of alternatives to consider, evaluate, and provide comments on, as required by statute and regulation. In failing to define Alternative Two as the real proposed action plan for the project you have systematically denied me the opportunity to review a fully articulated set of alternatives, sets of data, and analysis to review and comment about.

As stated at that time, I find the DEIS to be categorically deficient both in substance and methodology. I sincerely hope that you will honestly and competently consider the following comments, doing so can only improve the document.

/s/
Robert Barnes
P.O. Box 252
Hillsboro, New Mexico
88042

ABSTRACT: The numerous, and notable, deficiencies of the Copper Flat Copper Mine DEIS, fall within the twin categories of substance and methodology. This is a rare case, generally a document of this type - if it is poorly done - will be deficient in one or the other categories, but not both. Therefore, for each of the comments below I will explain the deficiencies as they have occurred in each category. Unless otherwise indicated, page and table numbers refer to Volume One of the DEIS. The documents footnoted in the body of these comments are provided in the Appendix.

SECTION ONE: WRITTEN AND VERBAL COMMENTS PROVIDED AT THE PUBLIC MEETING AT HILLSBORO, NEW MEXICO ON THE COPPER FLAT MINE DRAFT ENVIRONMENTAL IMPACT STATEMENT BY ROBERT A. BARNES ON 12/16/2015.

My name is Robert Barnes. I am a resident of Hillsboro, New Mexico and as such I am directly affected by the mining proposal made by THEMAC.

Given the limited amount of time made available for review of the draft Environmental Impact Statement my assessment of the document has been cursory. My statements at this forum are, therefore, general. More specific statements are being published on The Black Range Rag and will be provided to you in the formal comment process.

For many years I worked for years in policy and program arenas which required the use of NEPA mandated, and other public involvement, processes. I can say two things about those processes with a great deal of authority: 1) they are a pain in the ass; and 2) when done well the resulting decisions are significantly better than they would have been absent those processes.

Having sat on your side of the table, or at least watching my staff sit on your side of the table for years I have an appreciation of the political pressures you are under, I can appreciate the organizational culture which you work in, and I can appreciate that you may have limited capability to deal with complex issues.

The National Environmental Protection Act was not enacted to save the environment, it was enacted to protect the interests of the American people when they are faced with the well-financed and greedy aspirations of national and international corporations. NEPA, its implementing regulations, and various agency guidelines and procedures are designed to assure the availability of the best information possible in the decision making process.

This document fails in that regard. The methodologies, data sets, analytics, and conclusions of the parts of the report which I have reviewed - primarily the Surface Water Use, Groundwater Resources, and Socioeconomics sections are categorically deficient. The errors are rampant. Groundwater recharge is miscalculated because of fundamental flaws in basic assumptions; assertions of clay bed permeability given changing water gradients are unsubstantiated; the Region of Influence in the Socioeconomics section is inappropriately determined because the report fails to consider that copper prices and copper production function as standard commodities, responding to supply and demand in a fairly straight forward manner - meaning that Sierra County's gain is Grant County's loss and that out of all of this the tax revenue for New Mexico may not be any different than it already is; the misunderstanding of this area's economics and in particular the role of substantial business and tax revenues being generated by a stable, prosperous, and well-educated retirement community - a source of stable long-term funding for the county which is placed at risk by a large industrial complex being placed in an area people have sought out because of its tranquility leads to grossly erroneous economic conclusions; the sources of various data sets appear to be drawn from the press releases of the interested parties - an assessment of the Spaceport, for instance, fails to take into consideration the substantial taxes paid by the people of this region to construct the facility - not new money, redirected money, money which the people of the area could have used for different purposes.

In short, this document is substantively sophomoric, the document should be withdrawn and completely reworked because it is not fit for review.

Thank you.

Robert A. Barnes
December 16, 2015
Hillsboro, NM

SECTION TWO: ADDITIONAL COMMENTS PROVIDED ON FEBRUARY 29, 2016

COMMENTS ON CHAPTER 2 PROPOSED ACTION AND ALTERNATIVES

The subject DEIS fails to establish credible proposed actions and alternatives for analysis as required by Statute and Enabling Regulations.

In December of 2010, the New Mexico Copper Corporation (NMCC), acting for the Canadian Company THEMAC, submitted a Plan of Operations (MPO) for their proposed mine at the Copper Flat facility east of Hillsboro in Sierra County, New Mexico. They revised that plan in June of 2011. (page: abstract at front of DEIS)

On January 9, 2012 BLM published a Notice of Intent to prepare an EIS in response to the MPO. (p. ES-1) A Scoping Process to determine the parameters of the EIS was conducted between January 9, 2012 and March 9, 2012. (p. ES-2)

Federal Law requires that a Purpose and Need Statement be articulated in an EIS. BLM identified its Purpose and Need as follows:

> "The purpose of the BLM in relation to the proposed project is to manage the mineral resource within the Copper Flat mine to best meet the present and future needs of the American people in a balanced manner and to take into account the long-term sustainability of other resources and resource uses.
>
> The need for the BLM to authorize this project is established under the General Mining Law of 1872, as amended. Under this law, persons are entitled to reasonable access to explore for and develop mineral deposits on public domain land. As the Federal agency responsible for managing mineral rights and access on certain Federal land, the BLM must ensure that NMCC's proposal complies with BLM Surface Management Regulation (43 CFR 3809), the Mining and Mineral Policy Act of 1979 (as amended), and Federal Land Policy and Management Act of 1976." (p. ES-3)

The requirement to comply with other Federal Laws was not identified as a need in the DEIS.

Federal Law requires that BLM describe the Proposed Action evaluated by the EIS and Alternatives to the Proposed Action.

1. The Proposed Action identified in the NMCC submittal of 2011 described a mining operation which would process 17,500 tons of ore per day. (p. ES-4) This is the Proposed Action in the DEIS.

2. During 2011 and 2012, NMCC, identified an alternate plan of operations and this became Alternative 1 in the DEIS, it described a mining operation which would process 25,000 tons of ore per day. (p. ES-4)

3. During 2013, NMCC identified another alternate plan of operations and this became Alternative 2 in the DEIS, it described a mining operation which would process 30,000 tons of ore per day. (p. ES-4) In a public meeting held in Hillsboro on December 16, 2015, BLM identified this Alternative as the one preferred by THEMAC/NMCC, and it is listed as BLM's Preferred Alternative in the DEIS. This is the mine plan of operations which THEMAC describes on its website.

4. BLM described a "No Action" Alternative in its DEIS, as required by law. (p. ES-7)

BLM describes its evaluation of the Proposed Action and Alternatives as:

> "The Proposed Action was analyzed to adequately reflect the largest possible impact of the mining footprint at Copper Flat. At the conclusion of the EIS process, the MPO would be revised to accurately represent the Preferred Alternative selected by the BLM for the ROD." ES-4

As noted in BLM's Summary of Differences (p. ES-6) Alternative 2 (when compared with the Proposed Action); 1) increases the annual water use, 2) increases the total water uses over the life of the mine, and 3) power requirements increase (in this case, power from coal-fired electrical generation facilities). Even at the summary level, the Proposed Action does not "reflect the largest possible impact of the mining footprint at Copper Flat" - at the detail level, this discrepancy is even more obvious.

On page ES-9 of the DEIS, a table summarizing the impacts of the Proposed Action, Alternative 1, and Alternative 2 (the mining operation program described by THEMAC on its website as their plan of operation and the Alternative selected by BLM as its Preferred Alternative - see screen grab below from the [THEMAC website](http://themacresourcesgroup.com/copper_flat_mine) - http://themacresourcesgroup.com/copper_flat_mine - accessed on February 27, 2016).

MINING METRICS TABLE

Mine Life(years)	11.1
Strip Ratio(Waster:Ore Tons)	0.4:1
Lom annual processing rate(Ktons)	10,200
Copper equivalent annual production(Klbs)	74,000
Copper equivalent LOM production(Klbs)	819,000
Copper LOM annual production(Klbs)	57,000
Copper LOM production(Klbs)	628,000
Gold LOM annual production(Ktrozs)	20
Gold LOM production(ktrozs)	227
Copper equivalent LOM average grade	0.39%

The impacts are described only at a high level of summary: either Significant or Not Significant. The impacts are described for the Resources Areas identified in the report. The report does not provide data or analysis which would lead to the conclusions identified in this summary for most of the Resource Areas. The "No

Action" Alternative is not summarized in this table because BLM asserts that leaving the mine site as is has no impact in any of the Resource Areas. (p. ES-7) Pages 3-1 and 3-2 provide definitions for Significant and Not Significant.

Chapter 2 describes the Proposed Action and Alternatives 1 and 2. The description of mining operations in these three operational scenarios is adequate. Very general statements about the impacts on various Resource Areas are made in this chapter, in a number of instances these summary descriptions do not comport with findings elsewhere in the DEIS, are misleading, and/or suffer from errors of commission and omission. The No Action Alternative is not evaluated or even referenced.

The remainder of the report is dedicated to the assessment of the Resource Areas by BLM. There are serious concerns about the adequacy and accuracy of most of these assessments, those concerns will be addressed later.

The bulk of the analysis which BLM performed in each of the Resource Areas was premised on the Proposed Action. Their description of the differences between the analysis of the Proposed Action and the two Alternative Actions is limited to a paragraph or so. No assessment is made of the No Action Alternative.

This approach delivers a much different set of data, affects selected methodologies and analytic schemes, and arguably would lead to different conclusions than if the BLM had selected the mining plan of operations (Alternative 2) identified by THEMAC (and known to) BLM at the beginning of the process as the Proposed Action. This action was deliberate by BLM. The timing of submittals is such that there is no appropriate reason for the identification of a Proposed Action which did not meet the "reality test". (You know, the one that says if you are going to evaluate what someone is going to do you should evaluate what they are going to do - not something else.)

In their totality, the erroneously identified Proposed Action and Alternatives do not reflect a logical or likely set of options. Alternative 2, which should have been the identified Proposed Action is the most aggressive of all of the evaluated options. If it had properly been identified as the Proposed Action an additional (perhaps two) more aggressive option would have been identified and evaluated. The analysis performed in the DEIS would have been based on the the appropriate Proposed Action, the course of action identified as Alternative 2 in the DEIS. This analysis would have been performed using a different set of data and it would have delivered a different set of conclusions, across the board.

The decision made by BLM to not properly identify the Proposed Action results in a report which is deliberately skewed. It is not an appropriate assessment on which to make a decision on this topic. I have been denied the right, under statute, to review a Draft Environmental Impact Statement which identifies the Proposed Action and a set of viable alternatives by this action. In such cases, the Proposed Action is the action which is known to be the plan of operations of the project.

COMMENTS ON THE ASSESSMENT OF SURFACE AND GROUND WATER IMPACTS

The Canadian firm, THEMAC Resources Group Ltd, doing business as the New Mexico Copper Corporation proposes to use 1,238,885,502 (1.2 billion) gallons of fresh ground water every year to support its mining operations, known as the Copper Flat Copper Mine (p. 2-27, Table 2-11). The Bureau of Land Management proposes instead that it use 1,989,320,350 (2 billion) gallons of fresh water a year for its operations (p. 2-84, Table 2-30). As noted above the use of larger amounts of water on an annual basis is the Preferred Alternative presented by BLM and the stated course of operations by THEMAC, it is identified as Alternative 2 in the DEIS - it is not identified as the Proposed Action. As stated above, the alternatives were treated to only the most cursory analysis and the results of that analysis were not substantively discussed in the main body of the report. Thus denying the public an opportunity to appropriately evaluate the (real) Proposed Action.

According to the Canadian firm, the mining operations will require roughly 4 times the amount of fresh water described in the Proposed Action for its operations. THEMAC asserts that the difference (total water requirement minus fresh water) will be derived from several other sources, sources like the recovery of water from the tailings storage facility (p. 2-76). THEMAC asserts that it will be able to recovery 2,963,940,696 (3 billion) gallons of water from the tailings storage facility every year and reuse that water in its operations. (p. 2-27) Under the Preferred Alternative identified by the Bureau of Land Management (Alternative 2 in the report - and the real Proposed Action), THEMAC would have to recover 5,051,993,904 (5 billion) gallons of water a year for use in its operations (p. 2-84). The assertion that THEMAC can successfully recycle these amounts of water is fundamentally unproven, not adequately analyzed, and not discussed in the main body of the report (in part, because it was not the amount of water given the greatest amount of scrutiny - the analysis, to the extent that it exists, was performed on the lower amount of water because that was the amount identified for the Proposed Action in the report). Any shortfall in meeting these recycling goals will have to be made up with fresh water and will fundamentally effect surface and ground water supplies.

Even at the lowest projected fresh water use rates, the Bureau of Land Management finds that both Surface Water Use and Groundwater Resources will be adversely affected a "significant" amount. (p. ES-9) "Impacts to the regional water budget, including flows of the Rio Grande, would be significant. These impacts would be large in magnitude, long-term, and certain. Water budget impacts would begin to reduce once mining ends." (p. 3 - 96). Even after 100 years the reduced flow created by the mine would be 11,730,636 gallons a year. (3 - 83)

Over the 16 years of expected mine operations in the reports Proposed Action (p. 2 - 5), THEMAC projects a use of 19,641,646,578 (19.6 billion) gallons of fresh water. Alternative 2, which is the the BLM Preferred Alternative, and the Real Proposed Action 22,887,448,389 (22.9 billion) gallons of fresh water would be used (p. 3 - 27) during the 11 years the mine would operate (p. 2 -71). (It is unclear what the duration of mining operations are under the BLM proposal since it is variously reported as 11 years and 12 years (p. 2 - 72). The effects of using 22.9 billion gallons of water are not adequately accessed because of the fundamental flaw in methodology employed by BLM in its analysis (it is the lower amount of usage which received the "definitive" assessment and is discussed in the main body of the report).

Of significant importance is the assertion in the draft EIS that the aquifers will recharge in a fairly short period of time. At page 3 -14 the Bureau of Land Management asserts that "It is unlikely that global climate will change dramatically enough over the life of the project (approximately 16 years) to impact project activities." It is possible that this statement is true, the mining activities may not be affected by climate change phenomena. However, the effect of those climate changes, especially given the mining activities proposed by THEMAC, on a broad spectrum of EIS evaluation criteria may be extreme.

ALL FOOTNOTES ARE SUPPORTED BY FULL DOCUMENTATION IN THE APPENDIX TO MY COMMENTS. THE APPENDIX IS PROVIDED ONLY IN THE ELECTRONIC COPY OF THESE COMMENTS.

The recharge of the aquifers projected in the EIS is based on recent historical (straight-line) averages. This type of assessment has been roundly criticized in scientific literature for quite some time, see, for example *"Stationarity is Dead" - Long Live Transformation: Five Principles For Climate Change Adaption Law*; Robin Kundis Craig, Associate Dean for Environmental Programs, Florida State University College of Law; published in Vol. 34 **Harvard Environmental Law Review,** 9, 2010, pp. 9 - 73.[1] Dr. Julio Betancourt (Adjunct Professor, at the Department of Geosciences, University of Arizona and Senior Scientist, Branch of Regional Research, Water Mission Area of the USGS, and the recipient of numerous Federal and Private awards - cv available at wwwpaztcn.wr.usgs.gov/julio_cv.html) clearly articulated the clear methodological errors of straight line averages in various works including *"Stationarity is Dead; Whither Water Management?"* published in **Science**, Volume 319, pp 573-574, February 1, 2008.[2] Cook, Ault, and Smerdon published their findings about the recharge potential in the southwest in "*Unprecedented 21st Century Drought Risk In the American Southwest and Central Plains*" published in **Science Advances** (American Association for the Advancement of Science) on February 12, 2015[3]. The methodology which they use is typical of that which should be used in an analysis of this nature and application of this more appropriate methodology would result in markedly different results. If a more scientifically accurate assessment methodology were used, the negative impacts of mining operations on surface water and ground water would be significantly greater because the potential for recharge is so much less than that projected in the DEIS. These impacts will aggravate the negative economic impacts of the mine (something which the DEIS glosses over), namely the potential reduction of property values (because water supplies become more problematic), reduced revenue from property taxes for the county, and out migration of the more affluent members of the population (because they can).

In "The Impact of Climate Change on New Mexico's Water Supply and Ability to Manage Water Resources", July 2006 [4] the New Mexico Office of State Engineer and the New Mexico Interstate Stream Commission found that "The impacts to the State" (created by Climate Change) "are anticipated to be significant for water managers and users, with changes to both supply and demand including: ...changes in snowpack elevations and water equivalency...changes in available water volumes and in the timing of water availability...increasing precipitation in the form of rain rather than snow due to increasing temperatures...etc." (p. iv) None of these impacts are noted in the DEIS, all of these impacts will effect both the runoff and recharge of the aquifer.

At page 6 this report notes that "The recent observed decrease in snowpack in the Southwest has coincided with the warming trend. Climate models predict that snowpack in the Southern Rocky Mountains will continue to decline through the 21st Century." Snowpack is a major source of aquifer recharge. Not only will aquifers in this area not recharge as quickly as in the past, perhaps not recharging at all, following the drawdown by the proposed Copper Flat Mine, the activities of the subject project will aggravate climate change increasing the problem.

Increases in temperature will overwhelm any possible increase in precipitation. "The Impact of Climate..." (above) report notes (page 6) that a "7°(F) increase in temperature will require precipitation increases of 15 - 20% of current averages to mitigate the decrease in flows experienced from evaporative losses (Nash and Gleick, 1993). Additional research has also shown that increases in precipitation along with increased temperatures can result in decreases in runoff [Wolock and McCabe, 1999]." Even at substantially lower temperature increases the problem becomes insurmountable. Aquifer recharge and stability is becoming more and more problematic, even without a significant drawdown of the aquifer by a project like the Copper Flat Mine. The analysis contained in the DEIS is simply wrong, bad data, bad analysis, wrong conclusions.

In any proper assessment of a set of possible scenarios there is an analysis which includes probability curves (commonly referred to as "bell curves"). The most likely scenario is identified as that which is at the top of the probability curve. Less likely scenarios are identified by the "legs" of the bell curve, extended to the left and right of the most likely scenario. In the subject case, the most likely scenario, that aquifer recharge will be problematic in the future, certainly "irretrievable" and perhaps "irreversible"is found at the top of the bell curve. Scenarios in which everything is "just fine" are way out on the long legs of the probability curve. Yet it is one of these, drawn from the least likely set of scenarios, which the DEIS has selected as the anticipated outcome of mining operations at Copper Flat. This is reckless, capricious, and arbitrary.

These major errors of commission (in the methodology) and omission (failure to adequately consider the full range of negative economic impacts) result in an DEIS which is fundamentally flawed. Because these errors are so fundamental the Draft EIS should be withdrawn and reworked.

COMMENTS ON THE EFFECT OF THE PROPOSED PROJECT ON THE LOCAL ENVIRONMENT

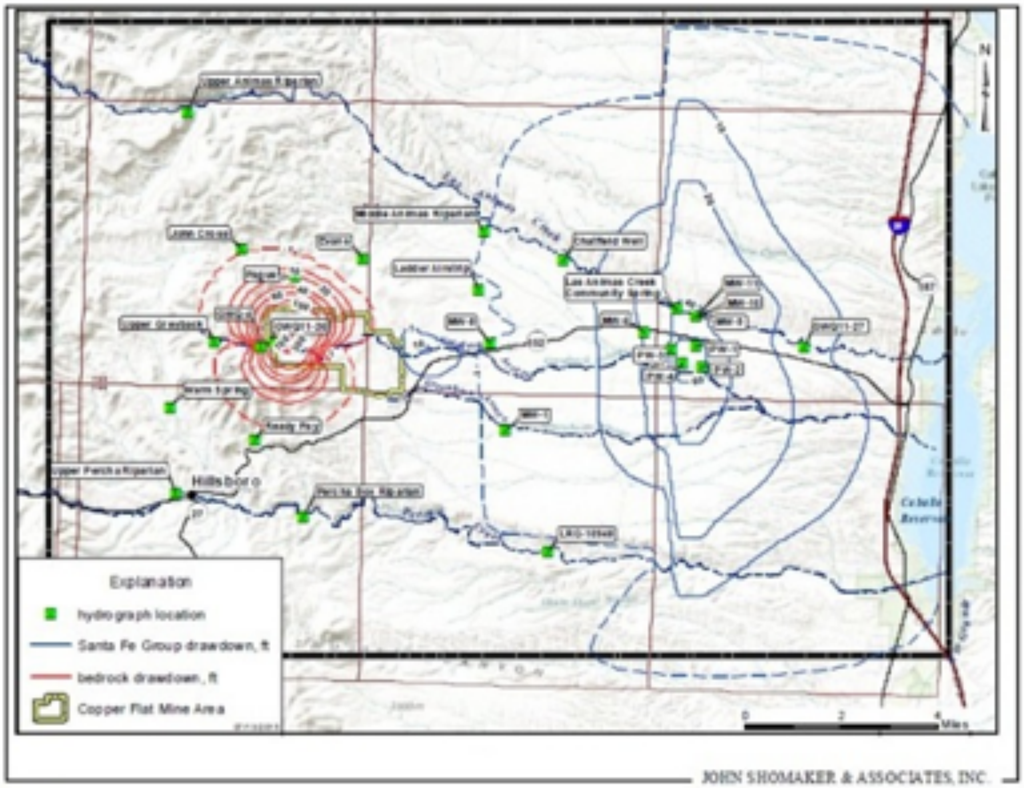
If you were to ask most of the people of the Rio Grande Valley what makes Hillsboro and the Animas Creek drainage so special, the answer would be "the trees". Our trees are what sets us apart from the rest of the area and most would argue that it is only the trees that set us apart. Some of us, in our hubris, might argue that we are part of the formula, but that is probably not accurate, people come to these areas of the Black Range because it is different from what they see out of their window every day not because of the people who live here.

The beauty of green trees suddenly emerging from the arid plain is breathtaking sometimes, the beauty of the fall colors in the Animas can be just as striking. But these trees live a tenuous life. Water, precious clean water, is in short supply in this area and the trees hang on only because they are able to reach it with their roots.

The Canadian firm, THEMAC, proposes to lower our water table significantly. It is quite likely their actions will kill our trees, especially those in the Animas.

In Alternative 2, the BLM preferred Alternative and the actual plan of operations identified by THEMAC, the BLM conservatively predicts that the water table in parts of the lower Animas will drop by at least 40′ (in areas nearby, 60′) as a result of THEMAC operations. (See Figure 3-19b, below, from the Draft EIS conducted by BLM, p. 3 - 92.) In the original proposal by THEMAC (they quickly changed there plans to that described in Alternative 2 - a cute bit of card play), the drawdown is not as dramatic, being only 20′ and 40′ respectively, but arguably just as damaging.

Figure 3-19b. Map of Water Level Declines in Layer 2 at End of Mining – Alternative 2



Source: JSAI 2015.

The BLM estimate of drawdown (in both the proposed action and the alternate actions involving mining) is extremely conservative because of flaws in the methodology used to calculate the damage.

THEMAC argues that the surface water of the Animas drainage is isolated from the Santa Fe aquifer by "a shallow clay layer that serves as a perching horizon that would isolate flows in Las Animas Creek from effects of pumping of the mine supply wells." (p. 3 - 63) This is a definite statement, as statements favorable to the mine operations are, throughout the report. Statements that are unfavorable to mining operations tend to be phrased in terms of "may" or "might", much less definite. The quality of the source data does not, however, appear to be different in the two situations (where favorable or unfavorable conclusions are reached), indicating systemic bias in the analysis. Please note, that this, in itself, does not indicate that the analysis reaches incorrect conclusions, except as noted elsewhere in these comments. It only indicates that the analysis is not rigorous, not as definitive as it claims to be in many places, and requires substantial testing to correct errors created by the obvious bias.

Even if the statement made by BLM about the presence of a clay layer creating a perched horizon (for the entire lower Animas) is correct, it is a great leap of faith to argue that it is isolated from the Santa Fe aquifer during, and following, mining operations. Permeability is a function of relative pressure gradients. When the Santa Fe aquifer is lowered by 60′ in the Animas Creek basin the ground water will be more likely to penetrate the ill-defined clay layers and flow directly into the Santa Fe aquifer than is the case currently. This will not affect the aquifer very much but it will dewater the Animas Creek basin and kill the trees.

Unfortunately, even within the BLM analysis construct, this is not the complete story. The BLM analysis indicates an additional lowering of the water table when the well owners in the Animas are forced to pump water, because of the drawdown, to maintain their current usage. (Figure 3 - 19c, p. 3 -93)

I believe that a thoughtful fact-based discussion of the proposed operation would be useful to the community. Unfortunately, the DEIS denies the community the opportunity for such a discussion because of its inherent bias. Making assertions does not make them fact, this is a fundamental truth that the BLM seems to have overlooked in this document. In basing its analysis on unproved assertions BLM has denied me the opportunity to review a fact-based DEIS.

The change of the tree colors as the seasons pass are an inherent part of the beauty of this area. This area of the Animas will be significantly harmed by Copper Flat Mining operations. A number of experts believe the trees will die as a result of the proposed mine operations.

COMMENTS ON THE ASSESSMENT OF SOCIOECONOMIC IMPACTS (3.22)

In one sense, the decision about the Copper Flats Copper Mine is very simple, does BLM want to impose:

1. The Mine Option: A short-term boom and bust economy over a period of twelve years followed by an economy which is less robust and stable than it is presently; or

2. The Long-Term Viability Option: Long-term, stable growth, based on prudent actions and maintaining the natural environment which has been the basis of an economy in which "the annual per capita income in Sierra County grew almost 30% faster than the State overall" (p. 3 - 241 & Table 3-61).

The rather astounding increase in per capita income in Sierra County documented by BLM in its DEIS is cause for celebration. At long last, we are beginning to pull ourselves from the bottom. And the emphasis is on "we", because this increase is despite the efforts of the County Government which have created an outflow of monies from the County (see Spaceport America discussion below). After documenting the increase in per capita income the BLM then makes a series of "interesting" determinations and reaches even more "interesting" conclusions. None of which appear to be able to stand up to any kind of scrutiny, simply making an assertion does not make it fact. And the onus is on BLM to demonstrate that at least some of their wild assertions are factual.

The DEIS states that the main economic drivers in Sierra County are "agriculture, healthcare, and tourism" (p. 3 - 241), completely ignoring the large and stable inflow of wealth into the county associated with the large, and growing, retirement community - arguably the driver of that growth in per capita income noted above. There has been an influx of retirees who are "well-heeled", they spend a lot of money in the county (increasing the wealth of other county residents and increasing the tax revenue of the county). In addition, their homes create new property tax income for the county (and property taxes which are greater than the county average). Suspiciously, the median value of owner-occupied housing units in the Hillsboro area are listed as "n/a" (p. 3 - 238, Table 3-57 "Housing Characteristics"). That data is, of course, easily accessible through the Sierra County Tax Office. At the BLM hosted meeting in Hillsboro, on December 16, 2015, it was noted by public presenters that the use of narrowly defined CDP's (Census Designated Place) are used in the report to exclude homes, businesses, and citizens who are located in the proximity of the mine (i.e., the 88042 zip code) from the analysis. It goes without saying, perhaps, that the effective disenfranchisement (the term used by presenters from the public at the referenced meeting) of these people and their economic activities supports an analysis favorable to BLM's preferred Alternative. This change in county economic demographics is completely ignored by the BLM in its assessment, creating a data base which is significantly incomplete. The resulting analysis and conclusions reached on the basis of the data actually included in the DEIS and analysis which flows from it is simply wrong. A house built on sand can not stand.

Instead, the DEIS attributes the growth to things like Spaceport America. In an assessment which, in large part, appears to be taken from one of Spaceport America's press releases, the impression is left that Spaceport America has been a positive economic driver for Sierra County, going so far as to quote the conclusions of future employment and expenditures included in the Final EIS for Spaceport America as evidence of economic growth (p. 3 - 242) (in case you missed the point - this DEIS uses predictions in the Final EIS for Spaceport America as evidence of economic growth - only one problem, those predictions have not panned out, and it is readily apparent and easily discernible that they have not). Parties which have less self-interest in the Spaceport (entities like the major media outlets in New Mexico, the industry group Parabolic Arc, and scores of public officials] are extremely concerned about the economic drain on Sierra County and the State of New Mexico (where bills to sell the facility because of its economic drain have been introduced in the State Senate). In excess of $142,000,000 in public funds have been spent on the Spaceport, much from a special gross receipts tax on the residents of Sierra County. The DEIS treats those funds as economic growth, those funds were not new money, they were redirected money. Redirected out of the pockets of Sierra County residents and into the pockets of contractors from outside the county, to support the activities of the very rich. Continuing expenditures, like $9,000,000 to the Florida company IDEAS drain wealth from Sierra County. The facility is currently running a $500,000 a year deficit, which is covered entirely by tax funds. The long-term outlook for the facility is dismal with better situated facilities built at the; Mojave Air and Space Port (www.mojaveairport.com); Spaceport Sweden (www.spaceportsweden.com); Mid-Atlantic Regional Spaceport (www.vaspace.org); Midland International Air & Space Port (www.midlandinternational.com); the British Commercial Spaceport; the Caribbean Spaceport (www.caribbeanspaceport.com); Cecil Field in Jacksonville, Florida; the Oklahoma Space Industry Development Authority (www.airspaceportok.com); and many others - Wikipedia lists more than 30 spaceports (not all of which are commercial, but could be). This example is given more space than it might otherwise be due because it is an example of the type of economic analysis which is present in the DEIS. Furthermore, Spaceport America did not even make the list of the county's 10 largest employers (p. 3 - 239) in the report. (Note, however, that it is unclear what the data set is for the 10 largest employers list, it may be Census Bureau data from 2007, Census Bureau data from the census of 2010, or from some other data set - simply another example of sloppy work in the report.)

Table 3 - 55, "Distribution of Population by Age" (p. 3 - 236) demonstrates the changing economy of Sierra County and especially the region near the mine (the 88042 zip code area). The economy has been shifting away from, and continues to shift away from, one driven by the cattle industry to one which is driven by the influx of retirees, people who are settling in the area because of its unspoiled natural setting. This change is extremely positive, creating an economy which is; stable in its source of wealth, effectively insulated from general economic swings, and which on a per capita income basis is greater than the rest of Sierra County and the State of New Mexico. Table 3 - 55 lists the percent of population older than 65 as 45.22% in the Hillsboro CDP (again a very narrowly defined area). The implicit notation in the report is that such a population is negative, when in fact it clearly demonstrates the economic shift in the area, a shift to a stable, affluent population which is effectively insulated from the whims of the general economy.

The economic stability and viability of the Hillsboro and Animas Creek areas is greater than the rest of Sierra County and most of the rest of New Mexico. This stability and viability is in grave danger of disappearing, however. The negative impacts of the mining operations on the environmental attributes that the retirement community cherish will destabilize this economic stability and viability and will have long lasting economic consequences.

Just when Sierra County is beginning to gain its economic footing, the underpinnings of that trend are swept away as if by a flash flood, property values diminish - reducing county tax revenues, people who came to the area because of its beauty will leave - taking their contributions to the county and business coffers with them, and I suspect they will not come back.

COMMENTS ON THE REVENUE STREAM DERIVED BY SIERRA COUNTY FROM THE PROPOSED MINE

At p 3-243 of the DEIS it is argued that the Copper Flat Mine will be subject to the processors tax but exempt from the resources tax because the ore would be processed in New Mexico - in the Hillsboro meeting on December 16, 2015, however, it was acknowledged that the ore will probably be processed outside of New Mexico. The DEIS analysis of tax revenue from the mine is, therefore, erroneous.

Property tax is due during periods when the mine is not operating, it is replaced during periods of operation by an ad valorem tax based on gross value of production. (p 3 - 244). The copper ad valorem tax is imposed on active copper production in lieu of the property tax, and is levied on the value of the mine and all real and personal property. Property tax and ad valorem tax revenue is added to the Copper Production Tax Fund which is distributed to taxing authorities by the state and the counties. At 3-245 the taxable value of copper production is listed, not the actual taxes paid, giving an erroneous impression of benefit.

At some point, this type of continuing misrepresentation of the benefits derived from the projected mine operations gets bothersome. It is very difficult to believe, that in its totality, this misrepresentation and obfuscation is accidental.

COMMENTS ON THE REVENUE STREAM DERIVED BY SIERRA COUNTY AND THE STATE OF NEW MEXICO FROM THE PROPOSED MINE

Copper is a commodity. This is a fact. The implications of this fact are not addressed, in any form in the DEIS. All tax revenues generated by the mine operations are

treated as additive (to the coffers of the county and state) in the report. That is not how tax revenues from commodities work. Currently, in southern New Mexico, there are two large copper mining operations. Their production affects the price of copper (and thus any revenue stream generated from their operations). Increases in copper production in the state will decrease the per unit revenue generated by copper production because the price of copper will drop. Thus, an increase in copper production, at the Copper Flat Mine will decrease the revenue from each unit of copper produced because the price of copper will drop (commodities are very responsive to supply and demand curves). It is certain that the revenue made available to Sierra and Luna Counties will diminish because of Copper Flat mine production. It is uncertain what the effect will be on State Revenues. It is improbable that they will increase if a third mine begins operations in the state. It is probable that the revenues will remain roughly the same, and possible that they will actually diminish. (This because the coppers future market is driven by perception as much as actual production.) There is no analysis of this phenomenon in the DEIS.

COMMENTS ON THE APPROPRIATENESS OF THE REGION OF INFLUENCE DETERMINATION

At page 3-235 the DEIS states "Since potential impacts with the greatest magnitude, duration, extent, and likelihood would occur in Sierra County, it is therefore defined as the Region of Influence (ROI) for the analysis of socioeconomic impacts. Impacts that extend outside of the ROI are discussed where applicable throughout the section".

As noted directly above, Grant and Luna counties are likely to suffer negative economic impacts as a result of the operations of the proposed Copper Flat Mine. Failure to address, these negative impacts and failure to include these counties in the Region of Influence effectively disenfranchises the citizens of those counties from commenting on the DEIS. They simply were ignored in any substantive public outreach efforts. In addition, because the economic effects of the three mines is integrated the economic analysis of the Copper Flat mine operations is fundamentally flawed.

The concept of ROI is not addressed in the water rights sections of this report. Diminishment of the water flow from the Percha and Animas drainages adversely affects all downstream users of water in the Rio Grande. This diminishment will have direct, and perhaps a very substantial negative effect, on the livelihood of those individuals. Again, this issue is not addressed in the DEIS and those individuals were not a target audience in any public outreach efforts.

SUMMARY

The BLM has denied me the opportunity to review the plan of operations of the Copper Flat Copper Mine and its implications. They have done so by performing an analysis of a plan of operations which they knew was not the actual plan of operations identified by the operator of the Cooper Flat Mine. The Proposed Plan should have reflected the known operating plan of the Copper Flat Mine, not what they submitted at the very beginning of the process, but the one that they publicly identified elsewhere (in roughly the same timeframe). The base analysis should have been made on the real plan of operations since that is the most extreme case and alternatives to that extreme should have been identified. None of this was done. The DEIS does not analyze the mining operations which the BLM knew, or should have known, were actually planned by the operator.

I spent my working life in the Federal Service, heavily involved in policy making, analysis, and public outreach. I am personally embarrassed by this DEIS.

/s/
Robert Barnes
Hillsboro, New Mexico
February 29, 2016

APPENDIX 1
Material Referenced in the Comments of Robert A. Barnes of Hillsboro, New Mexico
On The Draft Environmental Impact Statement for the Copper Flat Copper Mine

Footnote Number, Page Reference in Barnes Comments, and Title of Material	**Page Number in Appendix**
1. Referenced on page 9 of Barnes Comments. " "Stationarity is Dead" - Long Live Transformation: Five Principles For Climate Change Adaptation Law" by Robin Kundis Craig, Associate Dean for Environmental Programs, Florida State University College of Law; published in Vol. 34 **Harvard Environmental Law Review,** 9, 2010, pp. 9 - 73.	pp 2 - 67
2. Referenced on page 9 of Barnes Comments. ""*Stationarity is Dead; Whither Water Management?"* published in **Science**, Volume 319, pp 573-574, February 1, 2008	pp 68 - 69
3. Referenced on page 9 of Barnes Comments. Cook, Ault, and Smerdon published their findings about the recharge potential in the southwest in *"Unprecedented 21st Century Drought Risk In the American Southwest and Central Plains"* published in **Science Advances** (American Association for the Advancement of Science) on February 12, 2015.	pp 70 - 77
4. Referenced on page 10 of Barnes Comments. The Impact of Climate Change on New Mexico's Water Supply and Ability to Manage Water Resources" New Mexico Office of the State Engineer/Interstate Stream Commission July 2006	pp 78 - 144

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4. Referenced on page 8 of Barnes Comments. The Impact of Climate Change on New Mexico's Water Supply and Ability to Manage Water Resources" New Mexico Office of the State Engineer/Interstate Stream Commission July 2006	pp 78 - 144

"STATIONARITY IS DEAD"† — LONG LIVE TRANSFORMATION: FIVE PRINCIPLES FOR CLIMATE CHANGE ADAPTATION LAW

*Robin Kundis Craig**

While there is no question that successful mitigation strategies remain critical in the quest to avoid worst-case climate change scenarios, we have passed the point where mitigation efforts alone can deal with the problems that climate change is creating. Because of "committed" warming — climate change that will occur regardless of mitigation measures, a result of the already-accumulated greenhouse gases in the atmosphere — what happens to coupled socio-ecological systems over the next decades, and most likely over the next few centuries, will largely be beyond human control. The time to start preparing for these changes is now, by making adaptation part of a national climate change policy.

American environmental law and policy are not keeping up with the need for adaptation. For example, environmental and natural resources law are currently based on assumptions of ecological stationarity and pursue goals of preservation and restoration. Neither those assumptions nor those goals fit a world of continual, unpredictable, and nonlinear transformations of complex ecosystems — but that is the world that climate change is creating.

This Article argues for a principled flexibility *model of climate change adaptation law to pursue goals of increasing the resilience and adaptive capacity of socio-ecological systems. In so doing, it lays out five principles and several subprinciples for the law of environmental regulation and natural resource management. Structurally, this Article also strongly suggests that climate change adaptation law must be bimodal: it must promote informed and principled flexibility when dealing with climate change impacts, especially impacts that affect baseline ecological conditions such as temperature and hydrology, while simultaneously embracing an unyielding commitment to precautionary regulation when dealing with everything else.*

†P.C.D. Milly et al., *Stationarity Is Dead: Whither Water Management?*, 319 SCIENCE 573, 573 (2008).

* Attorneys' Title Professor of Law & Associate Dean for Environmental Programs, Florida State University College of Law, Tallahassee, Florida. I would like to thank Hope Babcock, Alex Camacho, Dan Cole, Dan Farber, Shi-Ling Hsu, Andy Klein, John Leshy, Wayne Logan, Dave Markell, G. Tracy Mehan, John Nagle (and his students), Hari Osofsky, Melanie Rowland, and J.B. Ruhl for their suggestions in response to drafts of this Article. However, I remain responsible for the final product, and comments may be directed to me at rcraig@law.fsu.edu.

INTRODUCTION

On Halloween, 2008, PBS's nightly news program *The NewsHour* reported the plight of Montana's $300 million recreational fishing industry and $2.4 billion agricultural industry, both of which depend on Montana's rivers and streams. Trout fishing makes up a substantial component of the fishing industry, but the trout begin to die when water temperatures reach 78°F or higher.[1] Unfortunately for the trout, average spring air temperatures have been rising since the 1950s, at a pace consistent with projected climate change impacts, and will continue to increase.[2] Higher temperatures mean earlier snowmelt and hence less and slower-moving water in the summer, which in turn allows instream temperatures to rise above the trout's tolerance[3] — and temperatures are expected only to keep increasing.[4] As for agriculture, the decrease in the total volume of water available during the summer makes irrigation increasingly difficult.[5] Thus, climate change appears to be simultaneously putting at risk Montana's trout, fishing industry, agriculture industry, and the human communities dependent on all three.[6]

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[1] *The NewsHour with Jim Lehrer: Montana: Trout and Drought* (PBS television broadcast Oct. 31, 2008), *available at* http://www.climatecentral.org/video/montana-trout-drought/.

[2] *Id.*

[3] *Id.*

[4] *Id.*

[5] *Id.*

[6] Climate change–related water issues are not limited to the United States. The World Bank reported on February 16, 2009, that "[c]limate change could eliminate all of Colombia's glaciers by the year 2030," and "that by 2050 Colombia would also experience less rainfall and higher temperatures on its mountain peaks," reducing the area of the wetlands that supply the capital city of Bogota with water by about 50%. Mike Ceaser, *Climate Change: World Bank Report Says Colombia's Glaciers Could Succumb to Global Warming by 2030*, BNA INT'L ENV'T DAILY, Feb. 25, 2009, http://climate.bna.com/Home.html (search "Mike Ceaser") (on file with the Harvard Law School Library).

As Montana's trout streams demonstrate, climate change[7] is already altering the base conditions of ecosystems in the United States and hence is beginning to impact the human economies that depend on those ecosystems' services. To list three additional recent examples:

- *Climate change is altering hydrological regimes, creating new and exacerbating existing conflicts between species' and humans' needs for water.* In May 2007, the U.S. District Court for the Eastern District of California noted that the Delta smelt, "a small, slender bodied fish endemic to" the Sacramento–San Joaquin Delta and already at risk from the joint operations of the federally managed Central Valley Project and California's State Water Project ("CVP/SWP"), would likely be put further at risk by climate change–driven decreases in water volume and increases in water temperature in the Delta.[8] Because the U.S. Fish and Wildlife Service ("FWS") failed to consider the effects of these changing hydrological conditions on the smelt, its Biological Opinion issued pursuant to the federal Endangered Species Act ("ESA") was arbitrary and capricious.[9] The resulting injunction threatened to shut down water delivery to millions of southern Californians[10] — indeed, delivery of water to southern California in summer 2009 (the start of the dry season) was only forty percent of users' expectations, a result of both continued drought and species considerations.[11] To complicate the water delivery prob-

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[7] As the Intergovernmental Panel on Climate Change ("IPCC") explained in 2007, "climate change" means:

> [A]ny change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the Framework Convention on Climate Change, where *climate change* refers to a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate variability observed over comparable time periods.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: IMPACTS, ADAPTATION, AND VULNERABILITY: CONTRIBUTION OF WORKING GROUP II TO THE FOURTH ASSESSMENT REPORT OF THE IPCC 6 (2007) [hereinafter IPCC, ADAPTATION REPORT].

[8] Natural Res. Def. Council v. Kempthorne, 506 F. Supp. 2d 322, 328, 365–70 (E.D. Cal. 2007).

[9] *Id.* at 370.

[10] Immediately after the district court's decision, state officials shut down the pumps that deliver water from the Delta to protect the smelt. *See* Glen Martin, *Smelt Decline Turns Off Delta Water Pumps; Official Says Users Relying on State Project Will Be Okay*, S.F. CHRON., June 1, 2007, at B1. Pumping eventually resumed, but at significantly reduced levels. *See* Jeanne Marie Kerns, *California Cuts Water Supply by a Third to Protect Endangered Delta Smelt Fish*, ASSOCIATED CONTENT, Sept. 2, 2007, http://www.associatedcontent.com/article/366070/california_cuts_water_supply_by_a_third.html (on file with the Harvard Law School Library).

[11] Bettina Boxall, *State Water Deliveries Up*, L.A. Times Greenspace Blog, May 20, 2009, http://latimesblogs.latimes.com/greenspace/2009/05/water-deliveries.html (on file with the Harvard Law School Library) (noting that delivery to water contractors was down to forty percent). These contractors include wholesalers who provide water to Southern California.

lem still further, in June 2009 the National Marine Fisheries Service ("NMFS") concluded that CVP/SWP operations are likely to jeopardize five other species protected under the ESA — the endangered Sacramento River winter-run Chinook salmon, the threatened Central Valley spring-run Chinook salmon, the threatened Central Valley steelhead, the threatened southern distinct population segment of North American green sturgeon, and Southern Resident killer whales — especially considering shifting ecological baselines for these species as a result of climate change.[12]

- *Climate change is already allowing destructive pest species to invade new territory, threatening both ecosystems and commercial interests.* As is true of most insects, "[e]very aspect of [the mountain pine beetle's] lifecycle is dependent upon temperature."[13] This pest invades pines, particularly lodgepole pines, and kills them.[14] The beetle's territory is normally limited by cold winters, but since the 1970s, warming temperatures have expanded the beetle's potential range by more than seventy-five percent.[15] Mountain pine beetles have been taking advantage of this new habitat in British Columbia, Canada, and the northern Rockies in the United States (especially Colorado and Wyoming), and the expansion of the species can only be explained by changes in climate.[16] By the end of 2006, the beetle had infested 130,000 square kilometers of British Columbia and western Canada, an invasion that is an order of magnitude larger than any previous invasion.[17] Moreover, between 1997 and 2007, the beetle destroyed thirteen million hectares of pine in this part of Canada,[18] many areas of which are considered critical timber supply areas.[19] To deal with the economic disruption that the infestation

Robert Krier, *State to Boost Water Deliveries to Wholesalers but S.D. Authority Won't See Increase*, SAN DIEGO UNION-TRIBUNE, May 21, 2009, at B4.

[12] SW. REGION, NAT'L MARINE FISHERIES SERV., NAT'L OCEANIC & ATMOSPHERIC ADMIN., BIOLOGICAL AND CONFERENCE OPINION ON THE LONG-TERM OPERATIONS OF THE CENTRAL VALLEY PROJECT AND STATE WATER PROJECT 575 (2009) [hereinafter NMFS, CVP/SWP OPINION], *available at* http://swr.nmfs.noaa.gov/ocap.htm.

[13] A.L. Carroll et al., *Impacts of Climate Change on Range Expansion by the Mountain Pine Beetle* 1 (Canadian Forest Serv. Mountain Pine Beetle Initiative, Working Paper No. 2006-14, 2006), *available at* http://warehouse.pfc.forestry.ca/pfc/26601.pdf.

[14] *Id.*

[15] *Id.* at 8.

[16] *Id.*

[17] Brian Hoyle, *Plight of the Pines*, NATURE REP. CLIMATE CHANGE, Apr. 24, 2008, http://www.nature.com/climate/2008/0805/full/climate.2008.35.html (on file with the Harvard Law School Library).

[18] *Id.*

[19] Under Canadian law, "[a] timber supply area is an area of Crown land designated by the minister of forests in accordance with the Forest Act and managed for a range of objectives including timber production." Forest Analysis & Inventory Branch, Ministry of Forests & Range, Gov't of British Columbia, Timber Supply Review, http://www.for.gov.bc.ca/hts/pubs/

and its effects on the Canadian logging industry have caused, the Canadian government "invest[ed] over $33 million in projects that support economic growth, job creation and future sustainability of communities adversely affected by the widespread beetle infestation."[20]

- *Climate change is creating positive feedback loops that may irreversibly push ecosystems over ecological thresholds, destroying coupled socio-ecological systems.* In January 2009, the U.S. Climate Change Science Program ("USCCSP") reported that the Arctic tundra represents a "clear example" of climate change pushing an ecosystem beyond an ecological threshold.[21] Warmer temperatures in the Arctic reduces the duration of snow cover, which in turn reduces the tundra's ability to reflect the sun's energy, leading to an "amplified, positive feedback effect."[22] The result has been "a relatively sudden, domino-like chain of events that result in conversion of the arctic tundra to shrubland, triggered by a relatively slight increase in temperature,"[23] and the consequences for people living in these areas have been severe. For example, the Inupiat Eskimo village of Kivalina, Alaska, is suing for the costs of moving elsewhere, in response to the steady erosion of the village itself.[24] Similarly, most Canadian Inuit live near the coast, on lands that exist only because of permafrost. Warming Arctic conditions threaten to deprive them of their homelands.[25]

brochure/tsacopy.htm (last visited Dec. 27, 2009) (on file with the Harvard Law School Library). Areas of British Columbia impacted by the mountain pine beetle include vast timber supply areas. Western Economic Diversification Canada, Mountain Pine Beetle: Community Economic Diversification Initiative, http://www.wd.gc.ca/eng/9622.asp (last visited Dec. 27, 2009) (on file with the Harvard Law School Library). These areas are of critical economic importance to the entire country: "Canada's log export trade is clearly dominated by British Columbia," largely because the region "contains forests unique in North America." BILL DUMONT & DON WRIGHT, GENERATING MORE WEALTH FROM BRITISH COLUMBIA'S TIMBER: A REVIEW OF BRITISH COLUMBIA'S LOG EXPORT POLICIES 11 (Dec. 2006), *available at* http://www.for.gov.bc.ca/het/logexportreview(v36).pdf.

[20] Western Economic Diversification Canada, *supra* note 19.

[21] U.S. CLIMATE CHANGE SCI. PROGRAM, SYNTHESIS & ASSESSMENT PRODUCT 4.2: THRESHOLDS OF CLIMATE CHANGE IN ECOSYSTEMS 2 (2009) [hereinafter 2009 USCCSP ECOSYSTEM THRESHOLDS REPORT].

[22] *Id.*

[23] *Id.*

[24] Yereth Rosen, *Village in Alaska Sues Energy Companies Over Erosion Linked to Warming Climate*, BNA STATE ENV'T DAILY, Feb. 29, 2008, http://news.bna.com/sedm (search "alaska sues") (on file with the Harvard Law School Library).

[25] James D. Ford, *Supporting Adaptation: A Priority for Action on Climate Change for Canadian Inuit*, 8 SUSTAINABLE DEV. L. & POL'Y 25, 28 (2008). While Antarctica has no permanent human settlements, it too is being impacted by climate change. Although the IPCC projected no significant warming on that continent over the next 50 years, more recent science shows "that on average the entire continent warmed by 0.5°C between 1957 and 2006." Catherine Brahic, *Antarctica Is Now Feeling the Heat of Climate Change*, NEW SCIENTIST, Jan. 21, 2009, http://www.newscientist.com/article/dn16460-even-antartica-is-now-feeling-the-heat-of-climate-change (on file with the Harvard Law School Library).

Thus, a variety of natural systems and the humans who depend on them — what are termed socio-ecological systems[26] — are vulnerable to climate change impacts.

While developing and implementing successful mitigation strategies clearly remains critical in the quest to avoid worst-case climate change scenarios, we have passed the point where mitigation efforts alone can deal with the problems that climate change is creating.[27] Because of "committed" warming — climate change that will occur regardless of the world's success in implementing mitigation measures, a result of the already accumulated greenhouse gases ("GHGs") in the atmosphere[28] — what happens to socio-ecological systems over the next decades, and most likely over the next few centuries, will largely be beyond human control. The time to start preparing for these changes is now, by making adaptation part of a national climate change policy.

Nevertheless, American environmental law and policy are not keeping up with climate change impacts and the need for adaptation.[29] To be sure, adjustments to existing analysis requirements are relatively easy, as when the Eastern District of California ordered the FWS to consider the impacts of climate change in its Biological Opinion under the ESA.[30] Agencies and courts have also already incorporated similar climate change analyses into the National Environmental Policy Act's ("NEPA") Environmental Impact Statement ("EIS") requirement[31] and similar requirements in other statutes.[32]

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[26] *See infra* Part I.B. "Socio-ecological systems, social-ecological systems, and coupled human-environmental systems are commonly used in the literature to describe systems of human-environmental interactions." Elinor Ostrom, Marco A. Janssen & John M. Anderies, *Going Beyond Panaceas*, 104 PROC. NAT'L ACAD. SCI. 15,176, 15,176 n.‖ (2007) (endnotes omitted).

[27] *See, e.g.*, Rasmus Heltberg, Paul Bennett Siegel & Steen Lau Jorgensen, *Addressing Human Vulnerability to Climate Change: Toward a "No Regrets" Approach*, 19 GLOBAL ENVTL. CHANGE 89, 89 (2009) ("Adaptation — adjusting to address ongoing and future climate changes — is increasingly recognized as an urgent and necessary complement to greenhouse gas emissions reductions."); W. Neil Adger et al., *Socio-Ecological Resilience to Coastal Disasters*, 309 SCIENCE 1036, 1039 (2005) ("Clearly, the reduction of greenhouse gas emissions is necessary in this context [coastal impacts] but not sufficient in the management of hazards in coastal regions."). *See also* Mireya Navarro, *New York Must Prepare for Global Warming, Mayor's Panel Says*, N.Y. TIMES, Feb. 18, 2009, at A23 (reporting the advisory panel's findings that planning was necessary to deal with "higher temperatures, more rain and an increased risk of coastal flooding").

[28] Maximilian Martin & Andreas Ernst, *Climate Change: Enlarging the Toolbox*, VIEWPOINTS 35, 39 (2008), *available at* http://ssrn.com/abstract=1322306 ("Existing CO_2 levels will persist for at least a century, with average global temperatures predicted to rise by up to 2°C regardless of steps taken to reduce GHG emissions.").

[29] For a summary of national and international adaptation efforts, see generally Ira R. Feldman & Joshua H. Kahan, *Preparing for the Day After Tomorrow: Frameworks for Climate Change Adaptation*, 8 SUSTAINABLE DEV. L. & POL'Y 61 (2007).

[30] Natural Res. Def. Council v. Kempthorne, 506 F. Supp. 2d 322, 328, 367–70 (E.D. Cal. 2007); *see also* Greenpeace v. Nat'l Marine Fisheries Serv., 55 F. Supp. 2d 1248, 1261 (W.D. Wash. 1999) (upholding NMFS consideration of climate change effects in its Biological Opinion for pollock fishery).

[31] *See* 42 U.S.C. § 4332(2)(C) (2006) (establishing that federal agencies must produce an EIS for any major federal action that may significantly affect the quality of the human environ-

Even so, adapting law to a world of continuing climate change impacts will be a far more complicated task than addressing mitigation. When the law moves beyond analysis requirements to actual environmental regulation and natural resource management,[33] it will find itself in the increasingly uncomfortable world of changing complex systems and complex adaptive management — a world of unpredictability, poorly understood and changing feedback mechanisms, nonlinear changes, and ecological thresholds. As noted, climate change alters baseline ecosystem conditions in ways that are currently beyond immediate human control,[34] regardless of mitigation efforts. These baseline conditions include air, water, and land temperatures; hydrological conditions, including the form, timing, quality, and amount of precipitation, runoff, and groundwater flow; soil conditions; and air quality. Alterations in these basic ecological elements, in turn, are prompting shifts and rearrangements of species, food webs, ecosystem functions, and ecosystem services.[35] Climate change thus complicates and even obliterates familiar ecologies, with regulatory and management consequences.

Nor are these regulatory and management consequences an as-yet-still-hypothetical problem. In February 2008, a group of researchers noted in *Science* that current water resource management in the developed world is grounded in the concept of stationarity — "the idea that natural systems fluctuate within an unchanging envelope of variability."[36] However, because of climate change, "stationarity is dead."[37] These researchers empha-

ment); Ctr. for Biological Diversity v. Nat'l Highway Traffic Safety Admin., 538 F.3d 1172, 1212–17, 1219–27 (9th Cir. 2008) (requiring agency to perform an adequate analysis of climate change effects to fulfill its NEPA responsibilities). *But see* City of Los Angeles v. Nat'l Highway Traffic Safety Admin., 912 F.2d 478, 485–90 (D.C. Cir. 1990) (upholding the agency's analysis of climate change and corporate average fuel economy ("CAFE") standards pursuant to NEPA).

[32] *See, e.g.*, Ctr. for Biological Diversity v. Brennan, 571 F. Supp. 2d 1105, 1130–36 (N.D. Cal. 2007) (finding the USCCSP in violation of the Global Change Research Act for failure to issue a climate change research plan); *see also* Found. on Econ. Trends v. Watkins, 794 F. Supp. 395, 396, 401 (D.D.C. 1992) (dismissing on standing grounds a suit seeking to force the Secretaries of the Interior, Energy, and Agriculture to analyze the effects of climate change on federal programs and actions pursuant to NEPA).

[33] Dan Farber, for instance, has pointed out that the EIS and other environmental assessments are purely reactive. Daniel A. Farber, *Rethinking the Role of Cost-Benefit Analysis*, 76 U. Chi. L. Rev. 1355, 1400 (2009).

[34] For example, as National Geographic News recently reported, "[w]armer water can hold less oxygen compared with cooler waters," and "as Earth's icy poles gradually transform into open oceans, new organisms, from plankton to shellfish, will move in," further depleting the oxygen there. Ker Than, *Global Warming to Create "Permanent" Ocean Dead Zones?*, Nat'l Geographic News, June 28, 2009, http://news.nationalgeographic.com/news/2009/01/090128-ocean-dead-zones.html (on file with the Harvard Law School Library).

[35] *See infra* Part I.B. Ecosystem services are the economically valuable services that functioning ecosystems supply to human beings. For example, watersheds capture sediments and other pollutants, protecting downstream water quality; riparian habitat "regulates water temperature" and wetlands "protect adjacent areas from the hazards of flooding." J.B. Ruhl, Steven E. Kraft & Christopher L. Lant, The Law and Policy of Ecosystem Services 5–6, 15 (2007).

[36] P.C.D. Milly et al., *Stationarity Is Dead: Whither Water Management?*, 319 Science 573, 573 (2008).

[37] *Id.*

sized that impacts to water supplies from climate change are now projected to occur "during the multidecade lifetime of major water infrastructure projects" and are likely to be wide-ranging and pervasive, affecting every aspect of water supply.[38] As a result, the researchers concluded that stationarity "should no longer serve as a central, default assumption in water-resource risk assessment and planning. Finding a suitable successor is crucial for human adaptation to changing climate."[39]

Further, these authors realized the critical question is what a successor regime to stationarity should look like.[40] With the onset of climate change impacts, humans have decisively lost the capability — to the extent that we ever had it — to dictate the status of ecosystems and their services. As a result, and perhaps heretically, this Article argues that, for adaptation purposes, we are better off treating climate change impacts as a long-term natural disaster rather than as anthropogenic disturbances,[41] with a consequent shift in regulatory focus: we cannot prevent all of climate change's impacts,[42] but we can certainly improve the efficiency and effectiveness of our responses to them. As this slow-moving tsunami[43] bears down on us, some loss is inevitable — but loss of everything is not. Climate change is creating a world of triage, best guesses, and shifting sands, and the sooner we start adapting legal regimes to these new regulatory and management realities, the sooner we can marshal energy and resources into actions that will help humans, species, and ecosystems cope with the changes that are coming.

The problem is, in this brave new world of climate change adaptation, there will be no panaceas — "one size fits all" solutions to environmental problems[44] — particularly in the realm of natural resource management. We

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[38] Specifically, they noted that climate change impacts will include "the means and extremes of precipitation, evapotranspiration, and rates of discharge of rivers," "atmospheric humidity and water transport," "flood risk," "contamination of coastal freshwater supplies" from sea-level rise, and "natural seasonal and interannual storage." *Id.*

[39] *Id. See also* Martin & Ernst, *supra* note 28, at 40 ("The management of water, air and other resources will become essential as the long-term impacts of warming become evident."); U.S. GLOBAL CHANGE RESEARCH PROGRAM, GLOBAL CLIMATE CHANGE IMPACTS IN THE UNITED STATES 49 (2009) [hereinafter USGCRP, IMPACT REPORT] ("Because climate change will significantly modify many aspects of the water cycle, the assumption of an unchanging climate is no longer appropriate for many aspects of water planning.").

[40] Milly et al., *supra* note 36, at 573–74.

[41] Of course, the distinction between "natural" and "anthropogenic" is often itself contested. *See, e.g.*, J.B. Ruhl, *The Myth of What Is Inevitable Under Ecosystem Management: A Response to Pardy*, 21 PACE ENVTL. L. REV. 315, 318–19, 320–22 (2004) (arguing that all ecosystems are influenced by humans); J.B. Ruhl, *The Pardy-Ruhl Dialogue on Ecosystem Management, Part IV: Narrowing and Sharpening the Questions*, 24 PACE ENVTL. L. REV. 25, 31 (2007) ("In short, naturalness is a human conception."). As this Article makes clear, however, I consider that contest to be unproductive and distracting for climate change adaptation efforts, including the implementation of climate change adaptation law.

[42] Again, this Article does not intend to undermine the critical role that mitigation can still play in reducing the severity and duration of climate change impacts. *See infra* notes 49–58 and accompanying text.

[43] My thanks to J.B. Ruhl for this metaphor, which I use with his permission.

[44] Ostrom et al., *supra* note 26, at 15,176 ("A core aspect of panaceas is the action or tendency to apply a single solution to many problems.").

need new ways of thinking about law, and a new legal framework that will allow a multiplicity of techniques to be brought to bear in crafting adaptation responses to particular local impacts while still promoting actions consistent with overall ecological and social goals.

Specifically, in formulating the law that will govern adaptation to ecological and socio-ecological impacts ("climate change adaptation law"), two issues are of most immediate consequence. First, existing environmental and natural resources laws are preservationist, grounded in the old stationarity framework that no longer reflects ecological realities.[45] In contrast, the new climate change adaptation law needs to incorporate a far more flexible view of the natural world, because both the identity of the regulatory objects — the things such as rivers that such statutes are trying to protect — and the regulatory objectives will themselves be continually transforming, especially at the ecosystem level.

Second, legal flexibility in the past has occasionally operated as the means for avoiding tough decisions and needed actions, as the Environmental Protection Agency's ("EPA") attempted ducking of carbon dioxide regulation under the Clean Air Act ("CAA") demonstrates.[46] Given the societal importance of climate change adaptation, however, increased legal flexibility should not become a mechanism for avoiding effective environmental regulation and natural resource management. To deal effectively with adaptation and climate change impacts, the law will need to differentiate aspects of flexibility and discretion. Specifically, the law will have to embrace flexibility and adaptive management in the implementation of specific adaptation measures. However, it will simultaneously need to limit actors' discretion to do nothing or to deviate materially from general regulatory and management precepts and goals. That is, the specific *means* of adaptation can reflect local circumstances and needs, but the *fact* of adaptation and the general *goals and policies* climate change adaptation law seeks to effectuate should not be subject to local veto or avoidance.

In other words, climate change adaptation law should be based on *principled flexibility*. As used in this Article, principled flexibility means that both the law and regulators (1) distinguish in legally significant ways uncontrollable climate change impacts from controllable anthropogenic impacts on species, resources, and ecosystems that can and should be actively managed and regulated, and (2) implement consistent principles for an overall climate change adaptation strategy, even though the application of those principles in particular locations in response to specific climate change impacts will

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[45] *See, e.g.*, Jonathan M. Verschuuren, Adaptation to Climate Change: Opportunities and Barriers 9 (May 2007) (unpublished manuscript), *available at* http://ssrn.com/abstract=1291183 ("[N]ature conservation law is aimed at conserving a certain habitat type, or certain species.").

[46] Notice of Denial of Petition, 68 Fed. Reg. 52,922, 52,925 (Sept. 8, 2003) (denying a CAA petition on grounds that EPA did not have authority to regulate greenhouse gas emissions under that statute).

necessarily encompass a broad and creative range of adaptation decisions and actions.

This Article takes a first step toward a new climate change adaptation regime for environmental regulation and natural resource management in the United States by suggesting an across-the-board shift in legal objectives, from preservation and restoration to the improvement of resilience and adaptive capacity.[47] Part I of this Article provides a basic introduction to the differences between climate change mitigation and climate change adaptation, as well as to the necessity of climate change adaptation. Part II then investigates the nature of climate change as *change* to argue that the paradigms of human-controlled preservation and restoration that currently saturate U.S. environmental and natural resources law are ill-suited to promoting efficient and effective adaptation to climate change impacts.

In Part III, the Article offers five principles (and several subprinciples) to guide climate change adaptation law. It acknowledges that these principles will have different implications for particular issues in environmental regulation and natural resource management. As one example, while natural resource management may need to become more flexible in key ways,[48] pollution control regulation may need to become more stringent and unyielding, perhaps even draconian. Nevertheless, this Article argues that, if employed with good faith in all of the relevant contexts, these principles will collectively increase the ability of species, ecosystems, and socio-ecological systems — and hence humans — to adapt more productively and efficiently to ongoing ecological changes in the United States.

I. Climate Change Adaptation Versus Climate Change Mitigation

A. *An Introduction to Climate Change Adaptation and Its Differences from Mitigation*

In the United States, much of the legal attention to climate change, whether expressed through litigation, legislation, or scholarship, has focused on *mitigation*[49] — that is, on the mechanisms for reducing global emissions of greenhouse gases, especially carbon dioxide,[50] and lowering the concen-

[47] Similar shifts have been advocated in other contexts. For example, authors from the World Bank have presented "an integrated approach to *increase the capacity of society to manage climate risks with a view to reduce the vulnerability of households and maintain or increase the opportunities for sustainable development.*" Heltberg et al., *supra* note 27, at 89.

[48] *See, e.g.*, Verschuuren, *supra* note 45, at 9 (arguing that "nature conservation law should be adapted to climate change, making it more flexible to deal with these changes, and at the same time making sure that authorities create and protect robust areas that can withstand the consequences of climate change").

[49] *See, e.g.*, Martin & Ernst, *supra* note 28, at 42 (lamenting that "the entire debate on climate change . . . remains focused on mitigation strategies").

[50] While carbon dioxide has received most of the attention, given the ubiquitous sources of that gas and its prominent role in climate change studies, several other greenhouse gases do

trations of those gases in the atmosphere.[51] For example, the *Massachusetts v. EPA*[52] litigation at the Supreme Court was about mitigation because it addressed EPA's authority and duty to regulate carbon dioxide emissions from motor vehicles.[53] Almost all of the climate change legislation and programs that the states, regional organizations, and Congress have been con-

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exist, including methane, chlorofluorocarbons, soot, and even water vapor. Cornelia Dean, *Emissions Cut Won't Bring Quick Relief, Scientists Say*, N.Y. TIMES, Jan. 27, 2009, at A21. However, carbon dioxide "is responsible for about half of greenhouse warming," and other greenhouse gases "are far less persistent in the atmosphere; if these emissions drop, their effects will decline relatively fast." *Id.*

[51] According to the U.S. Global Change Research Program, "[m]itigation refers to options for limiting climate change by, for example, reducing heat-trapping emissions such as carbon dioxide, methane, nitrous oxide, and halocarbons, or removing some of the heat-trapping gases from the atmosphere." USGCRP, IMPACT REPORT, *supra* note 39, at 10–11. The IPCC has adopted the mitigation goal of the 1992 United Nations Framework Convention on Climate Change ("UNFCCC"), namely:

> The ultimate objective of this Convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: MITIGATION 99 (2007) [hereinafter IPCC, MITIGATION REPORT] (quoting Article 2 of the Convention) (internal quotation marks omitted). The IPCC also has noted that "[t]he concept of 'mitigation potential' has been developed to assess the scale of GHG reductions that could be made, relative to emission baselines, for a given level of carbon price (expressed in cost per unit of carbon dioxide equivalent emissions avoided or reduced)." INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: SYNTHESIS REPORT: SUMMARY FOR POLICYMAKERS 14 n.15 (2007) [hereinafter IPCC, SYNTHESIS REPORT: SUMMARY FOR POLICYMAKERS] (emphasis omitted).

[52] 549 U.S. 497 (2007).

[53] *Id.* at 528–35. *See also* Ctr. for Biological Diversity v. Nat'l Highway Traffic Safety Admin., 538 F.3d 1172, 1212–15, 1219–27 (9th Cir. 2008) (addressing climate change issues related to the CAFE standards for vehicles); City of Los Angeles v. Nat'l Highway Traffic Safety Admin., 912 F.2d 478 (D.C. Cir. 1990) (upholding the climate change NEPA analysis for CAFE standards); Lincoln-Dodge, Inc. v. Sullivan, 588 F. Supp. 2d 224 (D.R.I. 2008) (addressing Rhode Island's adoption of greenhouse gas emissions standards for motor vehicles); Cent. Valley Chrysler-Jeep, Inc. v. Goldstene, 529 F. Supp. 2d 1151 (E.D. Cal. 2007) (addressing California's regulations regarding emissions of greenhouse gases from vehicles); Green Mountain Chrysler Plymouth Dodge Jeep v. Crombie, 508 F. Supp. 2d 295 (D. Vt. 2007) (addressing Vermont's adoption of California's greenhouse gas emissions standards for vehicles); Cent. Valley Chrysler-Jeep v. Witherspoon, 456 F. Supp. 2d 1160 (E.D. Cal. 2006) (addressing California's adoption of greenhouse gas emissions standards for vehicles); Nw. Envtl. Def. Ctr. v. Owens Corning Corp., 434 F. Supp. 2d 957 (D. Or. 2006) (addressing emissions of greenhouse gases that allegedly violated the CAA and increased the risk of various injuries to the plaintiffs); Connecticut v. Am. Elec. Power Co., 406 F. Supp. 2d 265 (S.D.N.Y. 2005) (addressing a nuisance suit against electric utilities based on their greenhouse gas emissions); Ctr. for Biological Diversity v. Abraham, 218 F. Supp. 2d 1143 (N.D. Cal. 2002) (addressing a demand for more alternative fuel vehicles under the Energy Policy Act); Okeson v. City of Seattle, 150 P.3d 556 (Wash. 2007) (addressing a challenge to a utility's program for mitigating greenhouse gas emissions); In re Matter of Quantification of Envtl. Costs, 578 N.W.2d 794 (Minn. App. 1998) (upholding the agency's calculation of environmental cost values from carbon dioxide emissions associated with electricity generation).

sidering or implementing are mitigation measures designed to reduce total emissions of carbon dioxide and other greenhouse gases.[54] Legal scholars, in turn, have debated the merits of the litigation, legislative, and programmatic efforts to reduce greenhouse gas emissions.[55]

Climate change mitigation efforts remain crucial, and this Article does not intend to suggest otherwise.[56] In 2007, the Intergovernmental Panel on Climate Change ("IPCC") reported that "[u]nmitigated climate change would, in the long term, be *likely* to exceed the capacity of natural, managed and human systems to adapt."[57] Thus, without mitigation efforts, mass destruction of both natural systems and human societies becomes an increasingly likely eventuality.[58]

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[54] In the month of January 2009, for example, the new Congress proposed a number of mitigation-related bills, including: Right to Clean Vehicles Act, H.R. 609, 111th Cong. (2009); Save Our Climate Act of 2009, H.R. 594, 111th Cong. (2009); Heavy Duty Hybrid Vehicle Research, Development, and Demonstration Act of 2009, H.R. 445, 111th Cong. (2009); H.R. 391, 111th Cong. (2009) (declaring that the CAA cannot be used to regulate greenhouse gas emissions or climate change); Cleaner, Greener, and Smarter Act of 2009, S. 5, 111th Cong. (2009); 21st Century Energy Independence Act of 2009, H.R. 260, 111th Cong. (2009) (promoting cellulosic ethanol technology development); Greenhouse Gas Registry Act, H.R. 232, 111th Cong. (2009); Green Energy Production Act of 2009, S. 137, 111th Cong. (2009). In contrast, only three bills proposed during the same period even remotely addressed climate change adaptation: Water Use Efficiency and Conservation Research Act, H.R. 631, 111th Cong. (2009); Environment and Public Health Restoration Act of 2009, H.R. 585, 111th Cong. (2009); Integrated Coastal and Ocean Observation System Act of 2009, H.R. 367, 111th Cong. (2009). However, in House Concurrent Resolution 2, Congress did express its opinion that the FWS should consider global warming and sea level rise in its species and ecosystem decisions. H.R. Con. Res. 2, 111th Cong. (2009). *See also* Posting of Catherine Ho to L.A. Times Greenspace, http://latimesblogs.latimes.com/greenspace/2009/02/western-clima-1.html (Feb. 18, 2009, 6:44 PM) (on file with the Harvard Law School Library) ("If Western states don't substantially reduce greenhouse gas emissions, they could face billions of dollars in health care and other related costs by 2020 . . . .").

[55] For recent examples, see generally Jason Scott Johnston, *Climate Change Confusion and the Supreme Court*, 84 NOTRE DAME L. REV. 1 (2008); Paula J. Schauwecker, *Land Use to Address Global Climate Change*, 23 NAT. RESOURCES & ENV'T. 48 (2008); *Emission Not Accomplished: The Future of Carbon Emissions in a Changing World*, 33 WM. & MARY ENVTL. L. & POL'Y REV. 1 (2008); Jonathan Zasloff, *The Judicial Carbon Tax: Reconstructing Public Nuisance and Climate Change*, 55 UCLA L. REV. 1827 (2008); Cass R. Sunstein, *The World vs. The United States and China? The Complex Climate Change Incentives of the Leading Greenhouse Gas Emitters*, 55 UCLA L. REV. 1675 (2008); Cary Coglianese & Jocelyn D'Ambrosio, *Policymaking Under Pressure: The Perils of Incremental Responses to Climate Change*, 40 CONN. L. REV. 1411 (2008).

[56] Matthew Zinn has adeptly critiqued what he calls "adaptation-preferring climate policies," arguing that "[a]n adaptation-preferring climate policy . . . risks creating a perverse synergy by failing to moderate the severity of climate change and its stresses on natural systems and simultaneously requiring adaptations that produce their own severe, and in some cases synergistic, impacts on these systems." Matthew D. Zinn, *Adapting to Climate Change: Environmental Law in a Warmer World*, 34 ECOLOGY L.Q. 61, 64 (2007).

[57] IPCC, SYNTHESIS REPORT: SUMMARY FOR POLICYMAKERS, *supra* note 51, at 19. *See also Summary for Policymakers, in* IPCC, ADAPTATION REPORT, *supra* note 7 [hereinafter IPCC, ADAPTATION REPORT: SUMMARY FOR POLICYMAKERS] (noting that "[a]daptation alone is not expected to cope with all the projected effects of climate change, and especially not over the long term as most impacts increase in magnitude").

[58] *See, e.g.*, USGCRP, IMPACT REPORT, *supra* note 39, at 9 (noting that "[i]f emissions continue to rise at or near current rates, temperature increases are more likely to be near the upper end" of the projections for 2100, which range from 2 to 11.5°F); JULIAN CALDECOTT,

At the same time, however, the IPCC noted that "[a]daptation is necessary in the short and longer term to address impacts resulting from the warming that would occur even for the lowest stabilisation scenarios assessed."[59] In other words, adaptation must become a co-strategy with mitigation efforts for dealing with climate change, because "[r]isks associated with climate change could greatly increase vulnerability unless adaptation is stepped up."[60] Moreover, adaptation efforts may have immediate benefits for socio-ecological systems by decreasing vulnerability to future changes, "reducing sensitivity to climatic risks," and increasing the adaptive capacity of both humans and the ecological systems upon which they depend.[61]

According to the IPCC, climate change adaptation refers to "the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities."[62] Ideally, these adjustments should "enhance resilience or reduce vulnerability to observed or expected changes in climate," such as "investment in coastal protection infrastructure to reduce vulnerability to storm surges and anticipated sea-level rise."[63] In practice, adaptation measures can be as broad-ranging as the scope of climate change impacts themselves; they can "include anticipatory and reactive actions, private and public initiatives, and can relate to projected changes in temperature and current climate variations and extremes that may be altered with climate change."[64]

Thus, whereas mitigation efforts focus on shaping human behavior to reduce the ultimate cause of climate change — increased greenhouse gas concentrations in the atmosphere — adaptation strategies must rely upon the (sometimes limited) abilities of species, ecosystems, and socio-ecological

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WATER: THE CAUSES, COSTS AND FUTURE OF A GLOBAL CRISIS 36 (2008) (citing a potential range of temperature increases of 1.1 to 6.4°C by the end of the century).

[59] IPCC, SYNTHESIS REPORT: SUMMARY FOR POLICYMAKERS, *supra* note 51, at 19.

[60] Heltberg et al., *supra* note 27, at 98. *See also* Verschuuren, *supra* note 45, at 1 ("Climate change is here to stay, at least for the time being. . . . So we have to adapt to the changing climate."); Thomas Lovejoy, *Mitigation and Adaptation for Ecosystem Protection*, 39 Envtl. L. Rep. (Envtl. Law Inst.) 10,072, 10,073 (2009) ("The adaptation part of the climate change agenda is only just beginning to get attention, and needs much more right away."); Paul Klemperer, What Is the Top Priority on Climate Change? 3 (Jan. 2009) (unpublished manuscript), *available at* http://ssrn.com/abstract=1328802 (noting that there is a greater than 20% probability that global warming will exceed 2°C — "the level that is commonly referred to as the threshold for 'dangerous' warming" — even if carbon dioxide levels in the atmosphere stabilize at 380 parts per million, a fairly ambitious goal); USGCRP, IMPACT REPORT, *supra* note 39, at 11 ("Mitigation and adaptation are both essential parts of a comprehensive climate change response strategy.").

[61] Ford, *supra* note 25, at 29.

[62] IPCC, ADAPTATION REPORT, *supra* note 7, at 6. *See also* USGCRP, IMPACT REPORT, *supra* note 39, at 11 ("Adaptation refers to changes made to better respond to present or future climatic and other environmental conditions, thereby reducing harm or taking advantage of opportunity."); Daniel H. Cole, *Climate Change, Adaptation, and Development*, 26 UCLA J. ENVTL. L. & POL'Y 1, 2 n.6 (2008) ("'Adaptation' is used to refer to efforts to deal with whatever consequences occur.").

[63] IPCC, ADAPTATION REPORT, *supra* note 7, at 720 (citations omitted).

[64] *Id.*

systems to respond to continuous alterations in baseline conditions.[65] Ecological literature describes these abilities through the closely related concepts of resilience and adaptive capacity. Resilience refers to the ability of a species, ecosystem, or socio-ecological system to cope with change. More precisely, resilience is:

> the capacity of linked socio-ecological systems to absorb recurrent disturbances such as hurricanes or floods so as to retain essential structures, processes, and feedbacks. Resilience reflects the degree to which a complex adaptive system is capable of self-organization (versus lack of organization or organization forced by external factors) and the degree to which the system can build capacity for learning and adaptation.[66]

Similarly, adaptive capacity refers to "the regenerative ability of ecosystems and their capability in the face of change to continue to deliver resources and ecosystem services that are essential for human livelihoods and societal development."[67] Resilience reflects a system's ability to absorb impacts and continue to function, while adaptive capacity refers to a system's ability to change to adjust to new conditions.

As a matter of international law, climate change adaptation is a component of the United Nations Framework Convention on Climate Change,[68] to which the United States is a party.[69] In particular, Article IV of the Convention requires parties to "cooperate in preparing for adaptation to the impacts of climate change."[70] While the parties to the Convention have pursued this duty less intensively than their duty to mitigate (as evidenced by the Kyoto

[65] *See, e.g.*, USGCRP, IMPACT REPORT, *supra* note 39, at 10 ("Society and ecosystems can adjust to climatic changes, but this takes time. The projected rapid rate and large amount of climate change over this century will challenge the ability of society and natural systems to adapt.").

[66] Adger et al., *supra* note 27, at 1036. *See also* Stella Hurtley, *Editor's Choice: Ecology: Resistance and Resilience*, 293 SCIENCE 1731, 1731 (2001) (noting that an ecosystem's "'resilience' is the extent to which it can recover after the source of change is removed"); Emma L. Tompkins & W. Neil Adger, *Does Adaptive Management of Natural Resources Enhance Resilience to Climate Change?*, 9 ECOLOGY & SOC'Y 1 (2004), http://www.ecologyandsociety.org/vol9/iss2/art10/ (arguing "that a system's capacity for resilience, which involves its ability to absorb perturbations without being undermined or becoming unable to adapt and learn, is an important element of any sustainable response to climate change").

[67] Adger et al., *supra* note 27, at 1036.

[68] U.N. Framework Convention on Climate Change, *opened for signature* May 9, 1992, S. Treaty Doc. No. 102-38, 1771 U.N.T.S. 164 [hereinafter UNFCCC].

[69] *See* Cole, *supra* note 62, at 2 n.2 (discussing the United States' potential treaty obligations); Verschuuren, *supra* note 45, at 1–2 (discussing the UNFCCC obligations and the Kyoto Protocol with respect to adapation).

[70] UNFCCC, *supra* note 68, art. IV(1)(e).

Protocol[71] and post-Kyoto negotiations[72]), they are beginning to pursue adaptation measures.[73]

Nevertheless, climate change impacts also create particular problems for specific places and peoples.[74] As such, a global legal response is insufficient to deal with the localized details of climate change impacts, which will require legal reforms at the national, state, and local levels as well. The next section reviews the kinds of climate change impacts that are occurring and likely to occur with this local/state/national nexus in mind.

B. *The Need to Turn Legal Attention to Climate Change Adaptation*

Climate change adaptation will be necessary for at least the next several decades, and probably centuries.[75] As the examples at the beginning of this Article demonstrate, climate change effects are already being felt,[76] and such impacts will continue to increase through at least the twenty-first century even if atmospheric greenhouse gas concentrations are stabilized quickly,[77] which is unlikely.[78] Continued climate change impacts are inevitable be-

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[71] Kyoto Protocol to the U.N. Framework Convention on Climate Change, Dec. 10, 1997, 37 I.L.M. 32.

[72] Information about the post-Kyoto negotiations and meetings is available through the United Nations' web site for the UNFCCC. United Nations, Framework Convention on Climate Change: Meetings, http://unfccc.int/meetings/items/2654.php (last visited Dec. 27, 2009) (on file with the Harvard Law School Library).

[73] For more detailed discussions of these measures, see Cole, *supra* note 62, at 5–7; Ford, *supra* note 25, at 26–28.

[74] *See* Cole, *supra* note 62, at 4 ("The costs of climate change are expected to rise during the course of this century, but those costs will not be distributed uniformly or equitably."); Verschuuren, *supra* note 45, at 3 ("Adaptation differs enormously depending on the exact local situation."); *see also* Ford, *supra* note 25 (focusing on climate change impacts on the Inuit).

[75] IPCC, Synthesis Report: Summary for Policymakers, *supra* note 51, at 14 (noting that "additional adaptation measures will be required to reduce the adverse impacts of projected climate change and variability, regardless of the scale of mitigation undertaken over the next two to three decades"). *See also id.* at 20 ("Even the most stringent mitigation efforts cannot avoid further impacts of climate change in the next few decades, which makes adaptation essential, particularly in addressing near-term impacts."); Ford, *supra* note 25, at 28; USGCRP, Impact Report, *supra* note 39, at 11.

[76] USGCRP, Impact Report, *supra* note 39, at 9 (noting that such changes "include increases in air and water temperatures, reduced frost days, increased frequency and intensity of heavy downpours, a rise in sea level, and reduced snow cover, glaciers, permafrost, and sea ice"); IPCC, Synthesis Report: Summary for Policymakers, *supra* note 51, at 9.

[77] IPCC, Synthesis Report: Summary for Policymakers, *supra* note 51, at 12.

[78] Indeed, the IPCC projects continued increases in greenhouse gas emissions of 25% to 90% from 2000 to 2030. *Id.* at 7. It also notes that:

> Future energy infrastructure investment decisions, expected to exceed US$20 trillion between 2005 and 2030, will have long-term impacts on GHG emissions, because of the long lifetimes of energy plants and other infrastructure capital stock. The widespread diffusion of low-carbon technologies may take many decades, even if early investments in these technologies are made attractive. Initial estimates show that returning global energy-related CO2 emissions to 2005 levels by 2030 would require a large shift in investment patterns, although the net additional investment required ranges from negligible to 5 to 10%.

Id. at 15.

cause carbon dioxide persists in the atmosphere for "'a few centuries, plus 25 percent . . . lasts essentially forever,'" and "[t]he warming from our . . . emissions would last effectively forever, too."[79] Thus, even if the world immediately implements comprehensive efforts to significantly reduce emissions of carbon dioxide and other greenhouse gases, there will be a substantial time lag between implementation of those efforts and either actual stabilization of greenhouse gas concentrations in the atmosphere or cessation of climate change impacts.[80] As a result, the world is probably already committed to a 2°C increase in average global temperature.[81]

One example of delayed climate change impacts will be sea level rise. Increased greenhouse gas concentrations in the atmosphere cause increased average global air temperatures. Much of this heat is transferred to the oceans, causing a slow expansion of their volume. At the same time, warming temperatures cause land-based ice and glaciers to melt, increasing the total amount of water in the seas. As a result, according to the IPCC:

> Sea level rise under warming is inevitable. Thermal expansion would continue for many centuries after GHG concentrations have stabilised, for any of the stabilisation levels assessed, causing an eventual sea level rise much larger than projected for the 21st century. . . . The long time scales of thermal expansion and ice sheet response to warming imply that stabilisation of GHG concentrations at or above present levels would not stabilise sea level for many centuries.[82]

Other climate change–driven alterations in ecological, meteorological, and climatic conditions will also be facts of life, at least until the end of this century and almost certainly much longer.[83]

Climate change adaptation is not only a long-term problem; it is a complex problem.[84] First, climate change is affecting atmospheric, land, freshwater, and ocean temperatures[85] — but not uniformly. Temperatures toward the poles are increasing faster than temperatures near the equator, and land temperatures are rising faster than temperatures in the ocean.[86] These temperature changes are already altering weather patterns, leading to fewer cold

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[79] Mason Inman, *Carbon Is Forever*, NATURE REP. CLIMATE CHANGE 156, 156–57 (2008) (quoting oceanographer David Archer). *See also* Dean, *supra* note 50 (noting that "the effects of carbon dioxide persist").

[80] Inman, *supra* note 79; Dean, *supra* note 50.

[81] CALDECOTT, *supra* note 58, at 37.

[82] IPCC, SYNTHESIS REPORT: SUMMARY FOR POLICYMAKERS, *supra* note 51, at 20. *See also* USGCRP, IMPACT REPORT, *supra* note 39, at 11 (noting that "the Earth's vast oceans have absorbed much of the heat added to the climate system due to the increase in heat-trapping gases, and will retain that heat for many decades").

[83] Inman, *supra* note 79; Dean, *supra* note 50.

[84] J.B. Ruhl & James Salzman, *Massive Problems in the Administrative State: Strategies for Whittling Away*, 98 CAL. L. REV. (forthcoming 2010) (manuscript at 4–6, 17, 19, 28–29), *available at* http://ssrn.com/abstract=1280896.

[85] IPCC, SYNTHESIS REPORT: SUMMARY FOR POLICYMAKERS, *supra* note 51, at 2.

[86] *Id.*

nights and frosts and more frequent hot days and hot nights, heat waves, heavy precipitation events, and "intense tropical cyclone activity in the North Atlantic."[87] As a result, climate change impacts will vary from location to location, necessitating different specific adaptation strategies in different places.[88]

Second, many of these climate change–driven ecological changes are likely to become both worse and more complex in the coming decades, because even the IPCC's fairly conservative analysis projects changes of 0.1°C to 0.2°C *per decade* for the rest of this century.[89] Contraction of snow- and ice-covered areas, increasing extreme heat events, increased intensity of tropical cyclones, and a poleward shift of such storms, are all likely results.[90] Water supplies are especially vulnerable:

> There is *high confidence* that by mid-century, annual river runoff and water availability are projected to increase at high latitudes (and in some tropical wet areas) and decrease in some dry regions in the mid-latitudes and tropics. There is also *high confidence* that many semi-arid areas (e.g. Mediterranean Basin, western United States, southern Africa and north-eastern Brazil) will suffer a decrease in water resources due to climate change.[91]

Moreover, as noted, changes in glacial, Arctic, and Antarctic ecosystems have already been observed as a result of changes in snow, ice, and frozen ground, while other areas are experiencing alterations in hydrological patterns and shifts of species poleward and upward, to higher elevations.[92] The IPCC concluded in 2007 that many other ecosystems are also likely to experience significant stresses and alterations as a result of climate change.[93]

Third, climate change impacts all sectors of socio-ecological systems. The changes in water resource availability alone will directly affect agriculture in low-latitude regions[94] and human health throughout the world.[95] Temperature impacts create a multiplicity of problems for humans and are already affecting several important economic and social activities, including: (1) agriculture, particularly with respect to the timing of spring planting and

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[87] *Id.*

[88] *See* USGCRP, IMPACT REPORT, *supra* note 39, at 107–52 (describing the differing regional changes in the United States).

[89] IPCC, SYNTHESIS REPORT: SUMMARY FOR POLICYMAKERS, *supra* note 51, at 7. *See also* IPCC, ADAPTATION REPORT: SUMMARY FOR POLICYMAKERS, *supra* note 57, at 19 ("Past emissions are estimated to involve some unavoidable warming (about a further 0.6°C by the end of the century relative to 1980–1999) even if atmospheric greenhouse gas concentrations remain at 2000 levels. . . .").

[90] IPCC, SYNTHESIS REPORT: SUMMARY FOR POLICYMAKERS, *supra* note 51, at 8.

[91] *Id. See also* USGCRP, IMPACT REPORT, *supra* note 39, at 41–52 (describing impacts to water resources and potential conflicts about water in the United States).

[92] INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, SYNTHESIS REPORT 33 (2007) [hereinafter IPCC, SYNTHESIS REPORT].

[93] IPCC, SYNTHESIS REPORT: SUMMARY FOR POLICYMAKERS, *supra* note 51, at 9.

[94] *Id.* at 9.

[95] *Id.* at 13 tbl.SPM.3.

the availability of a summer irrigation supply; (2) forest management, especially with respect to fires and pests; and (3) public health efforts, especially with regard to heat-related mortality, changes in infectious disease vectors such as mosquitoes, and changes in allergenic pollens.[96]

Climate change impacts operate on complex ecosystems and set in motion feedback loops and nonlinear changes, neither of which are entirely (or even mostly) predictable through existing knowledge and modeling. For example, one of the consequences of the mountain pine beetle's spread through Canada, with the resulting death of millions of acres of trees, is an increase in carbon dioxide emissions from the decaying trees and a decreased ability of the remaining forest to act as a carbon sink.[97] Researchers predict that the beetle's expansion and ravages — which are themselves almost certainly the result of early climate change impacts — may release 270 megatonnes of carbon dioxide by 2020, an amount that equals Canada's emission reduction commitment under the Kyoto Protocol.[98] This is an example of a positive feedback loop: increasing greenhouse gas concentrations in the atmosphere result in warming temperatures that allow the mountain pine beetle to expand its range, killing trees and resulting in increasing concentrations of carbon dioxide in the atmosphere, which will warm temperatures further and, at least for a while, allow the beetle to expand even farther northward.

Differential sensitivities of ecosystems add another layer of complexity to climate change impacts, and hence to adaptation strategies. Tundra, boreal forests, mountain regions, and the sea ice biome are primarily sensitive to warming, but Mediterranean-type ecosystems and tropical rainforests are most likely to be impacted by reductions in precipitation, while coastal ecosystems are most vulnerable to sea level rise and more severe storm events.[99] The most complex problems may occur in coral reefs, mangroves, and salt marshes, which will be impacted by several climate change–induced stresses — increased temperatures, sea level rise, and changes in water quality — simultaneously.[100]

Moreover, the crossing of ecosystem thresholds, like those in the Arctic tundra, and the conversion of ecosystems to new and probably irreversible states of being (e.g. the Arctic shrubland) is not only possible, but a source of real concern for the future. As the IPCC rather cautiously acknowledged, "[a]nthropogenic warming could lead to some impacts that are abrupt or irreversible, depending upon the rate and magnitude of the climate change."[101] More dramatically, but with a necessary sense of urgency, Ted Nordhaus and Michael Shellenberger have opined that:

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[96] *Id.* at 3.

[97] W.A. Kurz et al., *Mountain Pine Beetle and Forest Carbon Feedback to Climate Change*, 452 NATURE 987, 987 (2008).

[98] Hoyle, *supra* note 17.

[99] IPCC, SYNTHESIS REPORT: SUMMARY FOR POLICYMAKERS, *supra* note 51, at 9.

[100] *Id.*

[101] *Id.* at 13.

> To describe these challenges as problems of pollution is to stretch the meaning of the word beyond recognition. Global warming is as different from smog in Los Angeles as nuclear war is from gang violence. The ecological crises we face are more global, complex, and tied to the basic functioning of the economy than were the problems environmentalism was created to address forty years ago. Global warming threatens human civilization so fundamentally that it cannot be understood as a straightforward pollution problem, but instead as an existential one. Its impacts will be so enormous that it is better understood as a problem of *evolution*, not pollution.[102]

Given what we already know about climate change impacts, adaptation requires a constructive legal and social response to continuous, interacting, often unpredictable, and perhaps irreversible changes in multiple sectors. These changes affect the most basic elements of human support systems: water supply, agriculture, public health, ecosystem stability, and in some areas like the Arctic and coastal regions, the very existence of land to live on.[103] Nevertheless, comparatively little attention has been paid in the United States to the legal principles that should inform and govern climate change adaptation. Legal institutions need to begin to address adaptation challenges, and the sooner they do so, on a reasoned basis, the more proactive, rational, and cost-effective climate change adaptation measures can be. Moreover, while climate change adaptation efforts will need to pervade all aspects of law and society, a logical and manageable place to begin the discussion of climate change adaptation law is to set out principles for environmental regulation and natural resource management.

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[102] TED NORDHAUS & MICHAEL SHELLENBERGER, BREAK THROUGH: FROM THE DEATH OF ENVIRONMENTALISM TO THE POLITICS OF POSSIBILITY 8 (2007).

[103] IPCC, SYNTHESIS REPORT: SUMMARY FOR POLICYMAKERS, *supra* note 51, at 18 ("Key vulnerabilities may be associated with many climate-sensitive systems, including food supply, infrastructure, health, water resources, coastal systems, ecosystems, global biogeochemical cycles, ice sheets and modes of oceanic and atmospheric circulation."); *see also* Ford, *supra* note 25, at 28 (noting that "[t]he majority of Inuit cultural sites . . . and current settlements are located on the coast and/or on permanently frozen land (i.e., permafrost). Climate change threatens to violate Inuit rights to their homelands through sea level rise, coastal erosion, permafrost thaw, and more active slope processes."). The IPCC in 2007 identified five key "reasons for concern" related to adaptation: (1) "Risks to unique and threatened ecosystems"; (2) "Risks of extreme weather events"; (3) "Distribution of impacts and vulnerabilities"; (4) "Aggregate impacts"; and (5) "Risks of large-scale singularities." IPCC, SYNTHESIS REPORT: SUMMARY FOR POLICYMAKERS, *supra* note 51, at 19. *See also* IPCC, ADAPTATION REPORT, *supra* note 7, at 11–12 (detailing the potential climate change effects on freshwater resources and management; ecosystems; food, fiber, and forest products; coastal systems and low-lying areas; industry and human settlement; and human health); *id.* at 14–15 (detailing projected effects in North America).

C. *Mitigation Versus Adaptation as a Legal Problem*

Recognizing that environmental regulation and natural resource management should address the need for climate change adaptation is just the first step in adapting the relevant laws to the realities of climate change. As the previous discussion suggests, adaptation is inherently a far more complex legal problem than mitigation.[104] Despite some proposals (many sounding as though they came straight from science fiction) for short-term technological "fixes" to the problem of increasing greenhouse gas concentrations,[105] climate change mitigation efforts have one clear and essential regulatory goal: substantially reduce overall emissions of greenhouse gases worldwide, preferably sooner rather than later.[106] Even the basic regulatory mechanisms available to accomplish this goal are fairly limited in number: mandated reductions for each regulated emitter ("command-and-control" regulation), cap-and-trade programs, mandated changes in manufacturing processes, taxes and other economic incentives such as subsidies, or some combination thereof.[107]

Of course, the conceptual simplicity of mitigation law does not mean that creating and implementing such law will be easy. Indeed, the almost two decades of international negotiations on the subject and the failures of many nations to adopt mitigation laws attest to the numerous political, economic, technological, and practical difficulties in establishing a functional mitigation legal regime.[108] Participating nations have been less than success-

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[104] *See* Zinn, *supra* note 56, at 64 (discussing the complexities of climate change adaptation).

[105] Proposals have ranged, for example, from enlisting the ability of bony fish to produce calcium carbonate "gut rocks" to setting off volcanoes. *See* Catherine Brahic, *Fish 'an Ally' Against Climate Change*, New Scientist, Jan. 16, 2009, http://www.newscientist.com/article/dn16432-fish-an-ally-against-climate-change.htm# (on file with the Harvard Law School Library); *EPA Official: We May Need to Stimulate Volcanoes to Slow Down Global Warming*, Envtl. News Network, Feb. 16, 2009, http://www.enn.com/top_stories/article/39320 (on file with the Harvard Law School Library). These measures, however, do not address the root cause of climate change. To use a medical analogy, they treat the symptoms but not the disease itself.

[106] *See* IPCC, Mitigation Report, *supra* note 51, at 99.

[107] *See* Shi-Ling Hsu, Nine Reasons to Adopt a Carbon Tax 2–3 (May 8, 2009) (unpublished manuscript), *available at* http://ssrn.com/abstract=1405944.

[108] These difficulties include ongoing debates over which sources of greenhouse gas emissions to regulate, how severely and how quickly to regulate them, what other activities also need to be regulated, and what to do about global inequalities and the developing world, among others. These debates also reveal a multiplicity of perspectives regarding economic and social effects, technological capabilities, and equitable considerations in climate change mitigation efforts. For example:

> China and India long ago rejected any approach to addressing climate change that would constrain their greenhouse gas emissions or their economic growth . . . . The governments and the people of China and India are increasingly concerned about global warming, to be sure, but they are far more motivated by economic development, and to the extent that the battle against global warming is fought in terms of ecological limits rather than economic possibility, there's little doubt which path these countries will take.

ful in achieving their Kyoto Protocol commitments,[109] demonstrating that inertia remains an important practical limitation to mitigation progress and that new technologies and social norms are probably necessary before mitigation efforts can be successful.[110]

Even so, climate change adaptation law will be dealing with complexity at another order of magnitude because, as noted, the effects of climate change will themselves be complex — ever-changing, often unpredictable, and subject to feedback mechanisms that may not be completely understood and that may change over time, often leading to nonlinear alterations of ecosystems and their services. Moreover, adaptation law will have to cope with multiple layers of governmental interest, since many adaptation strategies will have to be intensely local in implementation, while adaptation principles and goals may need to operate on a larger state, watershed, regional, or national scale.

The complexity of climate change adaptation makes it both a more interesting and a more vexing legal problem than climate change mitigation. In the broadest perspective, adaptation measures must embrace all aspects of human society simultaneously, from national security to changes in economic productivity; from energy production and distribution to national and regional infrastructure redevelopment; from food production, distribution, and agricultural practices to water supply; from local government planning and land use regulation to environmental regulation and natural resource management.[111] Equally important, governments must implement whatever adaptation measures they choose while the ground is figuratively and literally shifting under society's feet — that is, while the focus of the adaptation measures itself may no longer have a stable identity.

NORDHAUS & SHELLENBERGER, *supra* note 102, at 12. As for other activities besides greenhouse gas emissions, "even if we were to drastically limit the greenhouse gas emissions produced by power plants and automobiles, we would still need a strategy to slow the rapid rate of deforestation." *Id.*

[109] As Ted Nordhaus and Michael Shellenberger have noted, "those developed nations that ratified the Kyoto treaty on global warming have made little headway in actually reducing their own emissions. In late 2006, the United Nations announced that, since 2000, the emissions of the forty-one wealthy, industrialized members of Kyoto had gone up, not down, by more than 4 percent." *Id.*

[110] *Id.* at 15 ("There is simply no way we can achieve an 80 percent reduction in greenhouse gas emissions without creating breakthrough technologies that do not pollute.").

[111] As the IPCC noted in 2007:

> The array of potential adaptive responses available to human societies is very large, ranging from purely technological (e.g., sea defences), through behavioural (e.g., altered food and recreational choices), to managerial (e.g., altered farm practices) and to policy (e.g., planning regulations). While most technologies and strategies are known and developed in some countries, the assessed literature does not indicate how effective various options are at fully reducing risks, particularly at higher levels of warming and related impacts, and for vulnerable groups. In addition, there are formidable environmental, economic, informational, social, attitudinal and behavioural barriers to the implementation of adaptation. For developing countries, availability of resources and building adaptive capacity are particularly important.

IPCC, ADAPTATION REPORT: SUMMARY FOR POLICYMAKERS, *supra* note 57, at 19.

Therefore, it is worth emphasizing that climate change adaptation law and policy, by definition, cannot be preservationist. The point should not be — and in many areas and sectors, *cannot* be — to preserve as much of the current status quo as possible, or even to make a shift to a new and stable status quo.[112]

Instead, even if we restrict our focus to environmental and natural resources law, as this Article does, climate change adaptation law will often require both a new way of thinking about what regulation is supposed to accomplish and different kinds of legal frameworks for accomplishing those new goals.[113] While I am less pessimistic than Matthew Zinn about the adaptability of environmental and natural resources law to climate change impacts (in part because I envision mitigation and adaptation as being simultaneous approaches), I agree with his conclusion that adaptation challenges both the existing capacity of legal institutions and continued public will to engage in environmental protection.[114] Environmental and natural resources law in a climate change adaptation era require fundamental re-visioning, because both regulatory goals and the legal mechanisms for accomplishing them will have to be centered on the concept of *change* itself. Responding effectively to the specific local and regional alterations occurring as a result of the global phenomenon of climate change requires a different paradigm for thinking about environmental, natural resource, and ecosystem "change" than those currently pervading most environmental and natural resources

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[112] *See, e.g.*, Farber, *supra* note 33, at 1401 (noting that in climate change adaptation, "the whole point is that the status quo will become unsustainable due to climate change"). *See also* J.B. Ruhl, *Climate Change and the Endangered Species Act: Building Bridges to the No-Analog Future*, 88 B.U. L. REV. 1, 18–23 (2008) [hereinafter Ruhl, *Building Bridges*] (describing how climate change is leading us to a "no-analog" future); J.B. Ruhl, *Thinking of Environmental Law as a Complex Adaptive System: How to Clean Up the Environment by Making a Mess of Environmental Law*, 34 HOUS. L. REV. 933, 940, 968–75 (1997) [hereinafter Ruhl, *Complex Adaptive System*] (arguing that environmental law inappropriately engages in uniformitarianism).

Nevertheless, while "[p]ublic opinion has largely accepted that climate change is occurring," "climate change is not yet considered irreversible and its long-term implications have not been accepted." Martin & Ernst, *supra* note 28, at 41. This lack of acceptance is obvious in the thrust of many of the few climate change adaptation articles that have been written, most of which adopt, consciously or unconsciously, a preservationist approach. *See, e.g.*, David Takacs, *Carbon Into Gold: Forest Carbon Offsets, Climate Change Adaptation, and International Law*, 15 HASTINGS W.-NW. J. ENVTL. L. & POL'Y 39, 43–44 (2009) (describing "ecological resiliency" as "*protecting and preserving* the natural ecosystems that help human communities survive through buffering from floods, filtering drinking water, stabilizing soil, providing sustainable forest products, and *preserving* a host of other ecosystem services necessary for human survival" (emphasis added)); William S. Eubanks II, *The Life-Altering Impacts of Climate Change: The Precipitous Decline of the Northeastern Sugar Maple and the Regional Greenhouse Gas Initiative's Potential Solution*, 17 PENN ST. ENVTL. L. REV. 81, 81 (2008) (arguing that "the public must first realize the scientific and economic necessity of *preserving* the sugar maple in the northeastern United States" (emphasis added)).

[113] IPCC, ADAPTATION REPORT, *supra* note 7, at 729–30, 731 (discussing the role of social processes in adaptive capacity, the potential role of regulation in building adaptive capacity, and the role of social policy in enhancing adaptive capacity).

[114] *See* Zinn, *supra* note 56, at 64–65, 81–101.

law. Thus, it is to our conceptualizations and theories of change that this Article now turns.

II. Thinking About Climate *Change*: Shifting Paradigms from Preservation and Restoration to Increasing Adaptive Capacity

A. *The Current Preservation and Restoration Paradigms*

At its most basic, "change" is the emergence of difference over time. Thus, acknowledgment of change almost by definition posits an initial or baseline state (or states) against which humans can measure the amount of difference that has accumulated over a particular period of time. Acknowledging change, in other words, is always an exercise in making comparisons.

More subtly, however, recognition of change also problematizes identity: how is it that we can identify the present "it" that has changed as being the same "it" that existed in a different state at some previous time? The point here is not to indulge in a philosophical inquiry into the nature of identity but rather to emphasize that climate change impacts can blur or obliterate the relevant identity of regulatory objects, particularly at the ecosystem scale.[115] Climate change impacts are metamorphic and transformative: Montana's trout streams become too warm to support trout; the Arctic tundra becomes the Arctic shrubland. As a result, climate change means that regulatory objectives based on the pre–climate change characteristics of particular places can and will become increasingly obsolete. Climate change adaptation law must be able to accommodate the transforming ecological realities of particular places and not attempt to freeze ecosystems and their components into some prior state of being.

Nevertheless, humans being humans, neutral valuations of the fact of change are rare, particularly when the articulation of "change" becomes interlaced with conceptions of "natural" and "unnatural" or "progress" (cleaner, restored) and "regression" (dirtier, degraded). In particular, natural changes, such as the cycles of seasons or the growth of babies, are generally good, or at least comfortingly predictable, and the histories of both science and literature reveal attempts to fit new discoveries and social developments into these comfortable tropes.[116] In contrast, anthropogenic changes

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[115] Ruhl, *Building Bridges*, *supra* note 112, at 17–26; Robin Kundis Craig, *Climate Change, Regulatory Fragmentation, and Water Triage*, 79 U. Colo. L. Rev. 825, 878–83 (2008).

[116] In science, for example, the evolution of the tropes of evolutionary theory are revealing, moving from the nineteenth-century conception of evolution as "progress" to the much more chaotic twentieth-century "punctuated equilibrium" view of species change. In literature, the English Romantic poets — arguably the first generation to have to cope with readily visible, non-natural environmental change, as a result of the Industrial Revolution — reached repeatedly for both mythological tropes of cyclical change and renewal and scientific notions of "progress" to explain and cope with the various "revolutions" of their day —

to the natural world, at least since the Industrial Revolution, are often portrayed as bad, from the English and American Romantic poets to Rachel Carson's *Silent Spring*,[117] in part because humans upset the "balance of nature."[118]

Thus, in general, human institutions in the Anglo-American tradition impose values on different types of change, and American environmental and natural resources law is no different. Indeed, one of the assumptions that pervades these laws is that anthropogenic change is unnatural and degrading, but also nontransformative and hence (generally) reversible. This assumption sets up the most basic paradigms of environmental and natural resource regulation and management: preservation and restoration. Laws implementing these paradigmatic goals, whether within the context of cleanups pursuant to the Comprehensive Environmental Response, Compensation or Liability Act[119] ("CERCLA," also known as "Superfund") or the establishment of marine protected areas,[120] attempt either to preserve an ecosystem in a desired, more "natural" state, or to reverse the human-induced changes in an area or ecosystem back to some more "natural" baseline.[121]

The restoration paradigm is perhaps clearest in pollution regulation, where the largely internalized baseline or assumed "pristine" condition is an area's preindustrial status, even though the relevant laws generally allow for some postindustrial compromise in the actual regulatory goal. For example, the federal Clean Water Act ("CWA") states a lofty (if unrealistic) "national goal that the discharge of pollutants into the navigable waters be eliminated by 1985."[122] However, its actual regulatory requirements are keyed to "best available" existing technological capabilities (in the form of technology-based effluent limitations)[123] and pragmatic water quality standards based on

Industrial, French, and American. Robin Kundis Craig, Romantic Transformations: The Poetics of Change and History in a Context of Mythography and Science 1–13 (March 17, 1993) (unpublished Ph.D. dissertation, University of California, Santa Barbara) (on file with the Harvard Law School Library).

[117] RACHEL CARSON, SILENT SPRING (1962).

[118] *See, e.g.*, DANIEL B. BOTKIN, DISCORDANT HARMONIES: A NEW ECOLOGY FOR THE TWENTY-FIRST CENTURY 8–13 (1990) (tracing a history of views of nature and the variety of metaphors used to described natural workings).

[119] 42 U.S.C. §§ 9601–9628 (2006).

[120] Of course, choosing the baseline can require consideration of practicalities and politics. *See* Robin Kundis Craig, *Taking Steps Toward Marine Wilderness Protection? Fishing and Coral Reef Marine Reserves in Florida and Hawaii*, 34 MCGEORGE L. REV. 155, 167–79 (2003). Nevertheless, the basic paradigm remains the same: return a changed (degraded) site or ecosystem to some previous state. *See id.* at 179–83.

[121] *See* NORDHAUS & SHELLENBERGER, *supra* note 102, at 24–26 (describing the model of pollution regulation in these paradigmatic terms and noting that most environmentalism operates off the metaphor that "[n]ature has been unjustly violated by mankind"). *See also* Richard J. Hobbs & Viki A. Cramer, *Restoration Ecology: Interventionist Approaches for Restoring and Maintaining Ecosystem Function in the Face of Rapid Environmental Change*, 33 ANN. REV. ENV'T & RESOURCES 39, 40 (2008) ("The practice of ecological restoration is becoming an increasingly important tool in humanity's attempt to manage, conserve, and repair the world's ecosystems in the face of an increasing legacy of environmental damage").

[122] 33 U.S.C. § 1251(a)(1) (2006).

[123] *Id.* §§ 1311(b), 1316, 1317(a).

the actual uses of particular waterbodies.[124] Nevertheless, the CWA's overall goal remains to "*restore and maintain* the chemical, physical, and biological integrity of the Nation's waters."[125]

Similarly, both CERCLA and the Oil Pollution Act[126] allow governments and tribes to collect natural resources damages for ecosystems impaired by releases of hazardous substances and oil spills, respectively, and the basic measurement of those damages is the cost of restoring the area to pre-spill or pre-release conditions.[127] Treatment, storage, and disposal facilities regulated under the Resource Conservation and Recovery Act ("RCRA") must undertake corrective actions if their activities contaminate land or groundwater,[128] restoring those sites to pre-contamination status; similarly, the Surface Mining Control and Reclamation Act seeks to ensure that mining operations restore the disturbed landscape to something approaching its pre-mining condition.[129] Finally, while the CAA less explicitly indulges in restoration rhetoric, it nevertheless seeks "to protect and enhance the quality of the Nation's air resources so as to promote the public health and welfare and the productive capacity of the population,"[130] fairly explicitly recognizing that industrialization can turn clean air into something unhealthy.

No one disputes that reducing pollution is generally a good thing. However, harnessing pollution regulation to goals formulated under a restoration paradigm creates a conceptual discontinuity with the realities of climate change impacts. Restoration is an attempt to return a resource to a prior ("normal" or "natural") state of being, a goal that climate change is likely to make impossible in many places. If increasing temperatures heat Montana's streams to the point where trout cannot survive, regulation of thermal pollution to restore the prior water quality is useless. This is the danger of the restoration paradigm: it can make environmental regulation appear futile in a climate change era, which it most decidedly is not. Indeed, as discussed below, reducing the amount of pollution entering the environment — particularly toxic pollution — should remain a critical component of the new law for climate change adaptation, but to serve different goals.

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[124] *Id.* §§ 1312, 1313.

[125] *Id.* § 1251(a).

[126] 33 U.S.C. §§ 2701–2762.

[127] *See* 42 U.S.C. § 9607(a)(4)(C) (2006) (creating liability for damage to natural resources caused by hazardous substances); 33 U.S.C. §§ 2702(b)(2)(A), 2706(b)(2)(A) (creating liability for damage to natural resources and allowing the President to name trustees to enforce such liability for the public good); 33 C.F.R. § 136.211(a) (2009) (noting that natural resources damages for the Oil Pollution Act include "the cost of restoring, rehabilitating, replacing, or acquiring the equivalent of the damaged natural resources"); 43 C.F.R. § 11.10(e)(3) (2008) (using the same language for natural resources damages under CERCLA).

[128] 42 U.S.C. § 6924(u), (v); 40 C.F.R. §§ 257.21–.28; 258.50, 258.51 (2009).

[129] 30 U.S.C. § 1265(a), (b)(2) (2006) (requiring mining permittees to "restore the land affected to a condition capable of supporting the uses which it was capable of supporting prior to any mining").

[130] 42 U.S.C. § 7401(b)(1).

Reducing pollution reduces ecosystem stress and vulnerability, increasing resilience — even if we cannot have exactly the same ecosystem that we had before.

Natural resources laws, in turn, tend to incorporate the preservation paradigm more prominently, generally through a focus on minimizing or mitigating destructive human change to ecosystems and species. Thus, NEPA forces federal agencies to think long and hard about any federal activity that might significantly affect the environment and to consider alternatives to the initial proposal that might be less environmentally damaging.[131] Reduction and mitigation of wetlands destruction are (or are supposed to be) a routine part of Section 404 permitting under the CWA,[132] while the overall goals of the ESA are to prevent the extinction of imperiled species and to restore them to populations that ensure that each species will thrive.[133] Multiple-use public lands management is more complex precisely because it anticipates and promotes continued human uses of public resources; nevertheless, the paradigm remains (legally, at least) to minimize human destruction of these resources.[134] Moreover, public lands managers have been moving toward an ecosystem management approach, with the goal of preserving ecosystem functions and services.[135] Similarly, management of water resources ("water law") generally anticipates continued human use of those resources, but the law increasingly imposes ecological restrictions on such uses through instream flow requirements, public interest requirements, and the public trust doctrine.[136]

Like the restoration paradigm, the preservation paradigm incorporates an expectation that ecosystems are or should be stable and that managers can sustain one particular historical ecological state of being. Thus it, too,

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[131] 42 U.S.C. § 4332(2)(C).

[132] 33 U.S.C. § 1344(a); 40 C.F.R. § 230.10(d).

[133] 16 U.S.C. §§ 1531(b), 1532(3) (2006); *see also* Ruhl, *Complex Adaptive System*, *supra* note 112, at 968–75 (discussing the "uniformitarian" approach of the ESA).

[134] *See, e.g.*, 43 U.S.C. § 1701(a)(8) (2006) (declaring a national policy that public land management "protect the quality of scientific, scenic, historical, ecological, environmental, air and atmospheric, water resource, and archeological values," "preserve and protect certain public lands in their natural condition," "provide food and habitat for fish and wildlife and domestic animals," and "provide for outdoor recreation and human occupancy and use"); *id.* § 1702(a) (defining "areas of critical environmental concern" to be public lands "where special management attention is required . . . to protect and prevent irreparable damage to important historic, cultural, or scenic values, fish and wildlife resources or other natural systems or processes, or to protect life and safety from natural hazards"); *id.* § 1702(c) (defining "multiple use" in part to be the "harmonious and coordinated management of the various resources *without permanent impairment of the productivity of the land and the quality of the environment*," paying attention to "the relative values of the resources and not necessarily to the combination of uses that will give the greatest economic return or the greatest unit output" (emphasis added)).

[135] *See, e.g.*, Robert L. Fischman, *The Significance of National Wildlife Refuges in the Development of Conservation Policy*, 21 J. LAND USE & ENVTL. L. 1, 14–22 (2005) (describing the 1997 conversion of National Wildlife Refuge management to an ecosystem-based approach).

[136] *See* Craig, *supra* note 115, at 835–36 and sources cited therein (discussing developments under both riparian and prior appropriation systems).

threatens to dislocate the goals of natural resources law from the ecological realities of a climate change era. Preserving natural resources implies an attempt to keep them in a particular state of being — another losing proposition as baseline conditions shift in response to climate change. Thus, goals based on a preservation paradigm, like those based on a restoration paradigm, threaten to render natural resources law futile. Instead, the new law of climate change adaptation needs goals that acknowledge and allow for ecosystem change.[137]

B. *The Mismatch of the Preservation and Restoration Paradigms with Climate Change Adaptation*

The preservation and restoration paradigms that currently pervade environmental and natural resources law assume that ecological change is predictable and that human impacts are generally reversible. Predictability is what makes human use of natural resources manageable and ecological preservation possible. If regulators can predict how a species, resource, or ecosystem will respond to changes in human impacts (more or less pollution, more or fewer people, more or fewer vehicles, more or less habitat destruction), they can manage that species, resource, or ecosystem to the human-determined functionality or productivity goal. Thus, we require drinking water contamination to be below maximum contaminant levels, manage fisheries for maximum sustainable yield, regulate air pollution to eliminate human health risks, and manage public lands to achieve sustained yield of several products and services. Reversibility, in contrast, presumes that undesirable ecological change can be undone. While some of the exceptions to this assumption are obvious — extinction of species, for example — the whole concept of environmental restoration depends upon it.

Neither of these regulatory and management assumptions holds true in a world of transformative climate change. As J.B. Ruhl has noted with respect to predictability, "even as we learn more about the highly coupled, tightly interacting processes that comprise the climate, the likelihood is that we will realize with even greater clarity that it is inherently unpredictable."[138] As for reversibility, the IPCC has emphasized that "[i]rreversibility is an important aspect of the climate change issue, with implications for mitigation and adaptation responses. The response of the climate system . . . is likely to be irreversible over human time scales, and

[137] USGCRP, IMPACT REPORT, *supra* note 39, at 11 (noting that "society won't be adapting to a new steady state but rather to a rapidly moving target. Climate will be continually changing, moving at a relatively rapid rate, outside the range to which society has adapted in the past.").

[138] Ruhl, *Building Bridges*, *supra* note 112, at 19; *see also id.* at 19–20 and sources cited therein; Heltberg et al., *supra* note 27, at 94 (emphasizing that historical data will provide no basis for predicting climate change impacts); Tompkins & Adger, *supra* note 66, at 1 ("The likely geographical distribution of impacts and the probabilities of particular future scenarios are much less clear.").

much of the damage is likely to be irreversible even over longer time scales."[139]

It might be argued that climate change merely exacerbates an existing problem in natural resource management: the law and managers assume stationarity and ignore how human impacts interfere with the natural dynamics of ecosystems, while the ecological reality has always been one of complex change.[140] Moreover, in some respects, the law has already been changing to reflect the dynamic complexity of natural systems. For example, Robert Fischman has explored in detail the evolution of the National Wildlife Refuge system to an ecosystem management framework in the context of refuges that are often undergoing systemic changes.[141] Finally, this dynamism means that species and ecosystems already possess some intrinsic ability to adapt to climate change.

However, the fact that the ecological dynamism/legal stationarity problem has been recognized before does not diminish the urgency to adopt climate change adaptation law and policy. First, while natural dynamism is indeed the rule, climate change–driven ecological transformations will almost certainly outpace natural dynamism in several respects — faster and greater accumulation of greenhouse gases than has ever occurred before; faster melting of polar ice and glaciers; more rapidly increasing air and water temperatures; abruptly changing air and ocean currents — with results that will be more dramatic and visible than "normal" ecosystem dynamics. Moreover, as a legal matter, the impacts of climate change on baseline ecological conditions extend far beyond endangered species and public lands management into environmental regulation (pollution control), energy law, agriculture law, and land use law. Thus, the dynamism/stationarity problem is arguably broader in a climate change era than has been fully acknowledged previously.

Second, while it is true that dynamism means that species and ecosystems have an intrinsic adaptive capacity, it is also true that (1) existing human impacts have already undermined that adaptive capacity and (2) ecological changes from climate change are already outstripping whatever adap-

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[139] IPCC, MITIGATION REPORT, *supra* note 51, at 102; *see also* Heltberg et al., *supra* note 27, at 94 (noting that irreversible damages are likely for both natural and human assets).

[140] *See, e.g.*, Robert L. Glicksman, *Ecosystem Resilience to Disruptions Linked to Global Climate Change: An Adaptive Approach to Federal Land Management*, 87 NEB. L. REV. 833, 836–37, 852–56 (2009) (describing the paradigm shift in ecology away from the equilibrium model and the mismatch of public lands laws, NEPA, and the ESA with the new dynamism); BOTKIN, *supra* note 118, at 4 (arguing that our perspective on nature must change to include "the recognition of the dynamic rather than the static properties of the Earth and its life-support system"); Ruhl, *Complex Adaptive System*, *supra* note 112, at 940, 954–67, 968–75 (explaining the dynamic qualities of ecosystems and other complex systems and exploring the uniformitarian nature of the ESA).

[141] Robert L. Fischman, *From Words to Action: The Impact and Legal Status of the 2006 National Wildlife Refuge System Management Policies*, 26 STAN. ENVTL. L.J. 77, 82–84 (2007); Fischman, *supra* note 135, at 14–22.

tive capacity remains.[142] Thus, humans cannot punt even the problem of species and ecosystem adaptation to climate change, especially if we acknowledge socio-ecological systems and our dependence on ecosystem services.

Third, and most importantly, although the dynamism/stationarity problem has been recognized,[143] the law has not changed significantly to acknowledge it. Problem recognized does not mean problem solved. Even though American courts are beginning to require regulators to discard the assumption of stationarity in the face of climate change, as in the Delta smelt case,[144] the preservation and restoration paradigms remain embedded in current environmental and natural resources law. Moreover, the perpetuation of these paradigms — both in the laws themselves and in the regulators' minds — impedes the rational development of climate change adaptation law and policy because they encourage decision makers to view ecological change as a matter of human choice: how much degradation will we choose to allow, and for what reasons? In the climate change era, in contrast, ecological change will result from both controllable human activities and the uncontrollable consequences of two centuries of greenhouse gas accumulation, and the law needs to reflect those new realities.

As noted, this regulatory perspective also indulges in yet another assumption, that ecological change is nontransformational. More specifically, current law assumes that, whatever humans do, the baseline attributes of the system — temperatures, precipitation and hydrology, soil conditions, air quality, species assemblage — will remain more or less intact. As this Article has discussed, however, climate change calls this basic assumption into question because it impacts precisely those baseline ecological attributes. We are moving into an era when ecological change may not be predictable and "when external factors, positive feedbacks, or nonlinear instabilities in a system cause changes to propagate in a domino-like fashion that is potentially irreversible."[145] As land, air, and water temperatures generally increase, patterns of precipitation change in terms of both amount and timing, and species shift as best they can to cope. As a result, "restoration" and even "sustainability" have the potential to become close to meaningless concepts. We are moving along an at least somewhat unpredictable path to an as yet unpredictable final destination — what J.B. Ruhl has called the "no-analog future."[146] Fundamental metamorphosis of the natural world,

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[142] IPCC, SYNTHESIS REPORT, *supra* note 92, at 65 ("There is *high confidence* that the ability of many ecosystems to adapt naturally will be exceeded this century. . . . Unmitigated climate change would, in the long term, be *likely* to exceed the capacity of natural, managed and human systems to adapt.").

[143] Ruhl, *Complex Adaptive System*, *supra* note 112, at 980–1000.

[144] Natural Res. Def. Council v. Kempthorne, 506 F. Supp. 2d 322 (E.D. Cal. 2007); *see also supra* notes 8–10 and accompanying text.

[145] 2009 USCCSP ECOSYSTEM THRESHOLDS REPORT, *supra* note 21, at viii.

[146] Ruhl, *Building Bridges*, *supra* note 112, at 17, 23.

and of the ecosystem services upon which human societies depend, is becoming our largely uncontrollable reality.

Thus, as was true more specifically for water resources management, stationarity is dead. If the law is to deal effectively with climate change, it must declare, at least with respect to climate change impacts, "Long live transformation."

And that leads to the last mismatch between the current legal paradigms of preservation and restoration and climate change adaptation law: our valuation of climate change–driven ecological change. From the adaptation perspective (but, importantly, *not* from the mitigation perspective), climate change impacts confound our normal understanding of what is "natural." Human industrialization may have set climate change in motion, but the planet's systems are responding in ways that we do not fully understand and at spatial and temporal scales that far exceed the scope of existing regulatory mechanisms. Impacts from climate change, for the next several decades at least, are largely beyond human control, regardless of human mitigation efforts. Obsessing about their "unnaturalness" is an unhelpful approach to formulating adaptation law.

Therefore, as heretical as it may sound, climate change adaptation law (but importantly, again, *not* climate change mitigation law) will almost certainly be more effective if it treats climate change impacts as though they were arising entirely from natural causes. Refusing to expend time, money, and analysis to figure out which changes are natural and which are not will keep climate change adaptation law focused on what is actually occurring with respect to species, water supplies, ecosystem functions and services, agriculture, disease vectors, and so on. Such a perspective will also keep society's limited resources directed toward productive responses to those changes, rather than ineffective and expensive attempts to restore a set of conditions that can no longer exist or inefficient efforts to address mitigation through adaptation's regulatory back doors.

As a corollary, I agree with J.B. Ruhl's conclusion that the ESA should not be used to attempt to address greenhouse gas emissions.[147] And I would extend that conclusion to all laws that do not directly focus on emissions of pollutants into air. That is not to say that legal arguments for doing so cannot be constructed — they can, and often easily. For example, under the CWA it would take no great effort to define greenhouse gas emitters as nonpoint sources contributing to temperature violations in Montana's trout streams and thus to include them within the ambit of any resulting total maximum daily load ("TMDL") regime.[148] That does not change the fact,

[147] *Id.* at 29–31, 59.

[148] *See* 33 U.S.C. § 1313(d) (2006) (setting up the TMDL requirement for waterbodies that violate water quality standards); *see also* Robin Kundis Craig, *Climate Change Comes to the Clean Water Act: Now What?*, 1 J. ENERGY, CLIMATE & ENV'T (forthcoming 2010), *available at* http://ssrn.com/abstract=1366065; Robin Kundis Craig, *The Clean Water Act on the Cutting Edge: Climate Change and Water Quality Regulation*, NAT. RESOURCES & ENV'T, Fall 2009, at 14 [hereinafter Craig, *The Cutting Edge*].

however, that the CWA TMDL process, like species protection regulation under the ESA, is a grossly inefficient mechanism for dealing with greenhouse gas emissions and the mitigation regulatory problem. Instead, policymakers, courts, and regulators should acknowledge that mitigation law and adaptation law address separate, if ultimately related, regulatory problems and need different sets of tools to do so.

C. *The New Paradigm: Increase Resilience and Adaptive Capacity*

Regulators' increasing inability to define regulatory goals in terms of previous (or even desired) ecosystem states and functions does not eliminate the role of environmental and natural resources law in the United States, nor should it become an excuse for an exploitative free-for-all. Instead, the more we acknowledge pervasive uncertainties regarding what climate change actually means at all levels — local, state, regional, or national; social, political, and natural — the more we should restructure environmental and natural resources law to give as many species and systems as possible the best chance to survive and adapt to whatever changes come. As the USCCSP recently concluded, "[I]t is essential to increase the resilience of ecosystems . . . and to employ adaptive management strategies to deal with new conditions, new successional trajectories and new combinations of species."[149]

As such, the new paradigm for environmental and natural resources law in an era of climate change adaptation must be to increase the continuing capacity of the natural world, human society, socio-ecological systems, and legal institutions to adjust to continual transformation. In other words, the overall goal of climate change adaptation law should be to increase humans', other species', society's, and ecosystems' *adaptive capacity*.[150]

The details of what this new paradigm means for particular statutes is beyond the scope of this Article, although some implications will be obvious. Instead, this Article seeks to establish a set of general principles that, individually and collectively, will help to promote adaptive capacity regard-

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[149] 2009 USCCSP ECOSYSTEM THRESHOLDS REPORT, *supra* note 21, at ix.

[150] According to the IPCC:

> Adaptive capacity is the ability or potential of a system to respond successfully to climate variability and change, and includes adjustments in both behaviour and in resources and technologies. The presence of adaptive capacity has been shown to be a necessary condition for the design and implementation of effective adaptation strategies so as to reduce the likelihood and the magnitude of harmful outcomes resulting from climate change. Adaptive capacity also enables sectors and institutions to take advantage of opportunities or benefits from climate change, such as a longer growing season or increased potential for tourism.

IPCC, ADAPTATION REPORT, *supra* note 7, at 727 (citation omitted). *See also* Heltberg et al., *supra* note 27, at 90 (advocating, as a new approach to adaptation management for households, "the explicit goal to *increase the capacity of society to manage climate risks with a view to reduce the vulnerability of households and maintain or increase the opportunities for sustainable development*" (emphasis added)).

less of the particular regulatory regime at issue. The next Part thus presents starting principles for legislatures and policymakers working to adopt climate change adaptation law.

III. Five Principles for Climate Change Adaptation Law

Altering the basic paradigms of environmental and natural resources law from preservation and restoration, based on assumptions of stationarity, to a paradigm of increasing resilience and adaptive capacity, based on assumptions of continuing, unpredictable, and nonlinear change, will necessarily require different kinds of legal amendments, and perhaps even new laws, for different regulatory contexts. Nevertheless, certain key principles should undergird the entire legal adaptation endeavor, regardless of the specific statute or level of government involved.

This Part lays out five key principles for climate change adaptation law. It presents those principles roughly in order of implementation. Because climate change impacts will occur over decades and probably centuries, governments cannot and should not develop complete adaptation strategies overnight, especially given current uncertainties regarding mitigation strategies and the particular climate change impacts likely to occur at the local level. Indeed, irreversible commitment too early to particular strategies as opposed to taking a more cautious, "no regrets" approach at the outset is more likely to create path dependencies[151] that could actually impede future adaptation and even survival.

Principle #1: Monitor and Study Everything All the Time

In general, "[e]nvironmental governance depends on good, trustworthy information about stocks, flows, and processes within the resource systems being governed, as well as about the human-environment interactions affecting those systems."[152] However, the unfortunate current reality is that we have very little idea what climate change impacts will actually be, especially at the local level.[153] Moreover, we have little understanding of "the com-

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[151] *See infra* text accompanying notes 305–15.

[152] Thomas Dietz, Elinor Ostrom & Paul C. Stern, *The Struggle to Govern the Commons*, 302 Science 1907, 1908 (2003). As one example, these researchers detailed how wrong information contributed to the collapse of cod stocks in Canada. *Id.*; *see also* Glicksman, *supra* note 140, at 871 ("Planning and project level decisions are only as good as the information on which they are based.").

[153] As researchers from the World Bank have described the climate change adaptation knowledge problem:

> There is a great deal of uncertainty about when, where, and how much predicted climate changes will manifest. Few problems confronted by social scientists and policy makers entail such complex long-term implications and this much uncertainty. Uncertainty complicates decision-making and cost-benefit analyses — should crop research, for example, target widely consumed staples or instead shift toward drought-tolerant varieties whose importance may grow? Uncertainty extends into

plex, multivariable, nonlinear, cross-scale, and changing [socio-ecological systems]" that exist even *prior* to climate change impacts.[154] Thus, Principle #1 for climate change adaptation law should be to increase requirements and funding for continual monitoring and basic scientific and economic research to promote understanding of climate change impacts at all scales and across sectors. This will help policymakers avoid overly simplistic "solutions" to, and panaceas for, climate change adaptation.

Anticipatory planning and actual responses to climate change impacts should be based on a solid scientific understanding of how ecological baseline conditions and ecosystem functions and services are changing, and on valid projections of such changes into the future (i.e., modeling).[155] Lack of knowledge about the nature, scope, and extent of climate change effects, particularly at the level of specific resources and ecosystems and local communities, limits citizens' and governments' abilities and willingness to make rational choices regarding adaptation strategies, thus undermining adaptive capacity.[156] In contrast, Lawrence Brown and Lawrence Jacobs have argued that "[w]hen faced with concrete threats, most Americans . . . expect government to intervene," creating more politically fertile ground for debate and creative solutions.[157] Nevertheless, solid information regarding both climate change impacts[158] and the costs and benefits of adaptation[159] remains quite limited.

One particular knowledge gap about which both the IPCC and the USCCSP have expressed deep concern is the potential crossing of ecological "thresholds" as a result of climate change.[160] As noted, one observed example of such threshold crossing has been the "conversion of the arctic tundra

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> the policy arena: levels of funding, implementation arrangements, and effectiveness of proposed adaptation interventions are all uncertain and contested. *Uncertainty, however, should not delay action.* When confronted with other risks such as health, food security, or the threat of terrorism, the response to uncertainty is not inaction as policy makers realize they need to minimize the risk of catastrophic losses. The same should be the approach to climate change.

Heltberg et al., *supra* note 27, at 94 (emphasis added). *See also* T.P. Hughes et al., *Climate Change, Human Impacts, and the Resilience of Coral Reefs*, 301 SCIENCE 929, 932 (2003) (calling for more research on coral reefs and noting that "most coral reef research is parochial and short-term, and provides little insight into global or longer-term changes").

[154] Ostrom et al., *supra* note 26, at 15,181.

[155] Elinor Ostrom has described a nested framework for studying the complexity of socio-ecological systems that could be helpful in the climate change adaptation context. *See id.* at 15,181–86.

[156] IPCC, ADAPTATION REPORT, *supra* note 7, at 719 (noting that barriers to the adoption of successful adaptation strategies include "significant knowledge gaps for adaptation as well as impediments to flows of knowledge and information relevant for adaptation decisions").

[157] LAWRENCE D. BROWN & LAWRENCE R. JACOBS, THE PRIVATE ABUSE OF THE PUBLIC INTEREST: MARKET MYTHS AND POLICY MUDDLES 130 (2008) (citation omitted).

[158] IPCC, ADAPTATION REPORT: SUMMARY FOR POLICYMAKERS, *supra* note 57, at 20.

[159] IPCC, ADAPTATION REPORT, *supra* note 7, at 724, 727.

[160] 2009 USCCSP ECOSYSTEM THRESHOLDS REPORT, *supra* note 21, at 1 ("[A]n ecological threshold is the point at which there is an abrupt change in an ecosystem quality, property, or phenomenon, or where small changes in one or more external conditions produce large and persistent responses in an ecosystem." (emphasis omitted)).

to shrubland, triggered by a relatively slight increase in temperature" and propelled by an "amplified positive feedback effect" that accelerates loss of snow cover.[161]

Such ecological thresholds represent limitations to the resilience and adaptive capacity of both ecosystems and coupled socio-ecological systems.[162] Indeed, the IPCC identifies threshold crossings as potential hard limits on both humans' and ecosystems' abilities to adapt to climate change,[163] and it cites the 2006 Millennium Ecosystem Assessment for the proposition that "[t]he loss of keystone species may cascade through the socio-ecological system, eventually influencing ecosystems services that humans rely on, including provisioning, regulating, cultural, and supporting services."[164]

Unfortunately, as has been noted, ecosystems and their responses to climate change are complex and difficult to predict.[165] Given the multiple complex interactions between climate change impacts and ecosystem function, the USCCSP has concluded that "[c]omplex situations like those involving ecological thresholds . . . tend to be beyond the limits of existing predictive capabilities."[166]

As a result, the USCCSP has strongly recommended monitoring and increased research as two means of identifying and hopefully avoiding these ecological thresholds.[167] Monitoring of "the key factors controlling adaptive capacity and resilience" is especially critical, and changes in monitoring priorities may be necessary.[168]

More generally, uncertainty regarding climate change impacts is a significant source of political and popular resistance to initiating climate change adaptation measures, particularly when such measures involve costly

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[161] *Id.* at 2.

[162] IPCC, ADAPTATION REPORT, *supra* note 7, at 733.

[163] *Id.*

[164] *Id.* at 734 (citing MILLENNIUM ECOSYSTEM ASSESSMENT, ECOSYSTEMS AND HUMAN WELL-BEING: SYNTHESIS (2006)).

[165] *See* Dietz et al., *supra* note 152, at 1908 ("Scientific understanding of coupled human-biophysical systems will always be uncertain because of inherent unpredictability in the systems and because the science is never complete."). The USCCSP has recently emphasized both that "[e]cosystems are not simple, and complex interactions between multiple factors and feedbacks can lead to even greater nonlinear changes in their dynamics" and that "climate change will alter not only the landscape, but it will also affect the disturbance mechanisms themselves." 2009 USCCSP ECOSYSTEM THRESHOLDS REPORT, *supra* note 21, at 3. The report continued, "[a]dding additional complexity to already-complex systems, human actions also interact with natural drivers of change, producing multifaceted ecosystem changes that have important implications for the services provided by those ecosystems." *Id.* at 3–4.

[166] *Id.* at 5.

[167] *Id.* at 6 ("Reliable identification of thresholds across different systems should be a national priority because of the potential for substantive surprises in the management of our natural resources.").

[168] *Id.* In particular, "[c]onsideration should be given to monitoring indicators of ecosystem stress rather than the resources and ecological services of management interest." *Id.*; *see also* W. GOVERNORS' ASS'N, WESTERN WILDLIFE HABITAT COUNCIL ESTABLISHED 29–30 (2008), *available at* http://www.westgov.org/wga/publicat/wildlife08.pdf (emphasizing the need for better data regarding wildlife species).

dislocations, changes in lifestyle or business conduct, or limitations on growth and sprawl. Increased knowledge bases — from increased monitoring of ecological conditions, improved modeling, and information sharing — will be necessary for a whole range of adaptation issues.[169] Even the IPCC has acknowledged that uncertainty regarding climate change impacts creates barriers to adopting and implementing effective adaptation measures,[170] and "[c]onflicting understandings can impede adaptive actions."[171]

Thus, increased knowledge about what climate change is doing to particular resources and ecosystem services can increase adaptive capacity by allowing specific changes to be identified and observed and hence making particular social impacts, especially economic impacts like those in Montana, more certain. Such knowledge can help to overcome political impediments to identifying and implementing adaptation measures.[172]

Principle #2: Eliminate or Reduce Non–Climate Change Stresses and Otherwise Promote Resilience

Principle #2 encompasses immediate, "no regrets" changes that legislatures and regulators can make to environmental and natural resources laws, even in the absence of detailed information about climate change impacts, that will nevertheless improve resilience and adaptive capacity. They are "no regrets" measures because, regardless of actual climate change impacts, they will reduce the toxicity of the environment, improve human health, and contribute to sustainability.

As the IPCC noted in 2007, "vulnerability to climate change can be exacerbated by other stresses."[173] In other words, ecosystems that are already coping with other problems, such as pollution, habitat destruction, and loss of biodiversity, are more vulnerable to climate change impacts than systems not already suffering from such stresses.

Many of these other stresses do not derive from climate change but instead from standard human-controlled activities, such as development and polluting industrial activities. These activities are amenable to the same "plain vanilla" regulation that currently characterizes environmental and natural resources law. Thus, by more stringently addressing these directly

[169] *See* Milly et al., *supra* note 36, at 574 (calling for improved modeling and "[r]apid flow of such climate-change information from the scientific realm to water managers").

[170] IPCC ADAPTATION REPORT, *supra* note 7, at 735 (citations omitted).

[171] *Id.* at 736.

[172] The IPCC has identified four such impediments: (1) the failure of increased knowledge about the causes and effects of climate change to lead to the adoption of adaptation strategies; (2) differing perceptions of climate change risks; (3) varying perceptions of vulnerability and adaptive capacity, which influence a person's willingness to undertake adaptation measures; and (4) the fact that guilt and fear do not work to motivate the initiation of adaptation responses. *See id.* at 735.

[173] IPCC, ADAPTATION REPORT: SUMMARY FOR POLICYMAKERS, *supra* note 57, at 19. More specifically, "[n]on-climate stresses can increase vulnerability to climate change by reducing resilience and can also reduce adaptive capacity because of resource deployment to competing needs." *Id.*

anthropogenic, non–climate change stressors, climate change adaptation law can do much to increase the resilience of ecosystems. Ecosystems so protected will generally have increased capacity to adapt to *climate change* impacts — to changes in temperature and other baseline ecological conditions — that humans will *not* be able to effectively regulate. In other words, while a pure restoration paradigm would unproductively encourage futile goals, climate change adaptation law should nevertheless seek to reduce or eliminate all of the existing stressors that it can in order to increase socio-ecological systems' resilience to climate change impacts that cannot be blunted.

The IPCC in 2007 identified coral reefs as one example of already over-stressed ecosystems. Reefs suffer from both non–climate change stressors such as overfishing, marine pollution, and chemical runoff from agriculture, and climate change-related stressors such as increases in water temperature and ocean acidification.[174] Thus, coral reefs are textbook examples of ecosystems where regulable stressors are compromising the systems' resilience to climate change impacts.

Marine biologists have emphasized that "the direct and indirect effects of overfishing and pollution from agriculture and land development have been the major drivers of massive and accelerating decreases in abundance of coral reef species, causing widespread changes in reef ecosystems over the past two centuries."[175] Fishing pressure disrupts coral reef food webs. Moreover, both removal of plant-eating fish through overfishing and nutrient pollution in agricultural runoff can promote the growth of destructive marine algae. Even before climate change impacts, therefore, these stressors "have caused ecological shifts, from the original dominance by corals to a preponderance of fleshy seaweed."[176] Seventeen marine scientists thus argued in *Science* that improving coral reefs' resilience in the face of climate change impacts "requires a strong focus on reducing pollution, protecting food webs, and managing key functional groups (such as reef constructors, herbivores, and bioeroders) as insurance for sustainability."[177] In other words, humans can greatly enhance coral reefs' ability to adapt to climate change by regulating and managing human-controlled non–climate change stressors.

In other systems as well, the existence of multiple stressors can undermine socio-ecological systems' adaptive capacities. In the IPCC's example, "farming communities in India are exposed to impacts of import competition and lower prices in addition to climate risks; marine ecosystems overexploited by globalised fisheries have been shown to be less resilient to climate variability and change."[178] In contrast, as the USCCSP has recently empha-

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[174] *Id.* (discussing the effect of temperature on coral reefs).

[175] Hughes et al., *supra* note 153, at 929 (citations omitted).

[176] *Id.* at 929, 932 (citations omitted). *See also* Adger et al., *supra* note 27, at 1037 (describing the same shift on some reefs).

[177] Hughes et al., *supra* note 153, at 932 (citations omitted).

[178] IPCC, ADAPTATION REPORT, *supra* note 7, at 719.

sized, reducing known stresses can "make ecosystems healthier and more resilient as climate changes."[179]

Several subprinciples follow from Principle #2.

1. *Decontaminate Land, Water, and Air, and Reduce New Pollution as Much as Possible*

Principle #2 strongly suggests that federal and state pollution control laws are important components of climate change adaptation law. By reducing the amount of pollution added to or left in land, water, and air, these regulatory regimes already reduce ecological stressors and hence contribute to overall resiliency.

As coral reefs demonstrate, however, pollution control laws do not yet adequately regulate all types and sources of pollution known to cause ecological harm. As one well-known example, nutrient pollution from agriculture not only damages coral reefs but also is the primary cause of the hypoxic zone ("Dead Zone") in the Gulf of Mexico and contributes to ongoing water quality and biodiversity problems in the Chesapeake Bay. Thus, amendments to the existing pollution control laws may be warranted to increase their contributions to socio-ecological systems' adaptive capacity. For example, some pollution control regulatory goals currently assume the ability of ecosystems and media to absorb certain amounts of pollution up to a human-determined qualitative standard, such as air quality requisite to protect human health under the CAA or the designated uses incorporated into CWA water quality standards. A goal of increasing adaptive capacity may prompt a shift in focus towards reducing new pollution to the greatest extent possible, and eliminating particular kinds of discharges and emissions to reduce pollution stressors even further.[180]

Numerous specific amendments should follow from this shift in focus. First, pollutants that are known to be stressors but that currently largely escape effective regulation, such as nutrient pollution of water,[181] should be brought within the ambit of the relevant regulatory regimes. Second, sources of pollution that are not being regulated effectively or comprehensively, such as nonpoint and agricultural sources of water pollution and minor stationary sources of air pollution, should be incorporated into the relevant regulatory regimes. Finally, instead of allowing pollution control requirements based on lesser standards of technological capability, such as the CWA's "best conventional control technology"[182] and the CAA's "rea-

[179] 2009 USCCSP ECOSYSTEM THRESHOLDS REPORT, *supra* note 21, at 7.

[180] For example, Dan Farber has recommended radical reform of the federal Toxic Substances Control Act to follow the European model. *See* Farber, *supra* note 33, at 1358, 1374–79.

[181] NAT'L RESEARCH COUNCIL, MISSISSIPPI RIVER WATER QUALITY AND THE CLEAN WATER ACT: PROGRESS, CHALLENGES, AND OPPORTUNITIES 36–45, 126–28 (2008).

[182] 33 U.S.C. § 1311(b)(2)(E) (2006).

sonably available control technology,"[183] legislatures might incorporate both more demanding standards based on the best available technologies and incentives for continual innovation in pollution control technologies and manufacturing processes with technology-forcing regulatory requirements. Similarly, EPA could make greater use of its existing authorities to reduce or ban releases of toxic pollutants into the environment, as through CWA effluent standards[184] and CAA revisions of maximum achievable control technology-based emissions standards.[185]

On the other side of pollution regulation, the new goal of increasing adaptive capacity suggests that governments should direct more money and effort toward cleaning up existing contamination on land and in waterbodies, particularly along coasts, in floodplains, and in likely corridors of ecosystem shifting and adjustment. I have already discussed, for example, how reducing coastal contamination will both improve efforts to adapt to sea level rise and decrease the damage to coastal areas from Hurricane Katrina–like storms.[186] However, CERCLA's cleanup program has faltered recently.[187] Recent bills introduced in Congress to revive the Superfund tax to fund CERCLA cleanups[188] are thus a step in the right direction.

2. *Convert "Maximum Sustainable Yield" and Similar Regulatory Standards to "Clearly Sustainable Even Under Climate Change" Standards*

Regulatory standards based on "sustainable yield" or "sustained yield" pervade U.S. natural resources law. For example, fisheries management under the Magnuson-Stevens Fishery Conservation and Management Act seeks to achieve "maximum sustainable yield."[189] Federal land agencies such as the U.S. Forest Service and Bureau of Land Management ("BLM") manage national forests and other public lands under "multiple-use sustained-yield" legal regimes, including the Multiple-Use Sustained-Yield Act

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[183] 42 U.S.C. § 7502(c)(1) (2006).

[184] 33 U.S.C. § 1317(a).

[185] 42 U.S.C. § 7412(d)(2).

[186] *See* Robin Kundis Craig, *A Public Health Perspective on Sea-Level Rise: Starting Points for Climate Change Adaptation*, 15 WIDENER L. REV. (forthcoming 2010) (manuscript at 21–28), available at http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1119563.

[187] The Public Interest Research Group ("PIRG") reported in 2004 that:

> [Superfund] cleanups have fallen by 50 percent during the Bush administration compared with the pace of cleanups between 1997 and 2000. Site listings have slowed down as well; the Bush administration has listed an average of 23 Superfund sites a year compared with an average of 30 sites from 1993 to 2000, a drop of 23 percent.

JULIE WOLK, U.S. PIRG EDUC. FUND, THE TRUTH ABOUT TOXIC WASTE CLEANUPS: HOW EPA IS MISLEADING THE PUBLIC ABOUT THE SUPERFUND PROGRAM 1 (2004), *available at* http://www.uspirg.org/home/reports/report-archives/toxic-free-communities.

[188] *E.g.*, Superfund Polluter Pays Act, H.R. 832, 111th Cong. (2009); Superfund Reinvestment Act of 2009, H.R. 564, 111th Cong. (2009).

[189] 16 U.S.C. §§ 1802(33), (34), 1852(g)(1)(B), 1853(a)(3) (2006).

of 1960,[190] the Forest and Rangeland Renewable Resources Planning Act of 1974,[191] and the Federal Lands Policy and Management Act.[192] "Sustained yield" under these statutes, like "maximum sustainable yield" in fisheries, promotes "high-level annual or regular periodic output" of timber and other renewable resources.[193]

However, one of the more troubling legacies of natural resource management in the United States is that "sustainable yield" standards tend to err on the side of more human harvest or extraction rather than institutionalizing any kind of precautionary principle or margin of error in favor of the species or ecosystem. Thus, even before climate change, these natural resource management regimes rarely achieved true "sustainable" use of the relevant resources. Instead, "maximum sustainable yield" and similar standards allow more harvest and taking than is truly sustainable. Indeed, U.S. fisheries are widely acknowledged to suffer from overfishing,[194] and Julian Caldecott has recently noted that "[c]atastrophic over-fishing worldwide is rooted in our trying to achieve 'rational' use, based on an inadequate understanding of wildlife populations and ecology."[195] He has also described in detail the pervasive flaws that help to ensure "that the [maximum sustained yield] approach will result in exhausted fisheries and a largely dead ocean."[196] Similarly, Robert Fischman has concluded that, for national forests, multiple use sustained yield "tilted toward maintaining commodity outputs at the expense of ecological integrity."[197]

As in coral reef ecosystems, overharvest of living resources creates additional stress for the ecosystems of which they are a part, impairing or destroying ecosystem functions and services and increasing the ecosystem's vulnerability to climate change impacts. In contrast, "[b]iodiversity enhances resilience if species or functional groups respond differently to environmental fluctuations, so that declines in one group are compensated by increases in another."[198] As such, making harvest standards *truly* sustainable would increase ecosystems' resilience and decrease their vulnerabilities, even in the absence of climate change impacts.

Climate change impacts further problematize the whole concept of "sustainable yield." How do regulators decide what a sustainable take might be when species are rearranging and ecosystems are transforming all

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[190] *See id.* § 529.
[191] *Id.* § 1604.
[192] 43 U.S.C. § 1701(a)(7) (2006).
[193] 16 U.S.C. § 531(b); 43 U.S.C. § 1702(h).
[194] *See, e.g.*, Peter Schikler, *Has Congress Made It Harder to Save the Fish? An Analysis of the Limited Access Privilege Program (LAPP) Provisions of the Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006*, 17 N.Y.U. ENVTL. L.J. 908, 910 (2008) (noting that American fisheries management is unsustainable).
[195] CALDECOTT, *supra* note 58, at 79.
[196] *Id.* at 81–83.
[197] Robert L. Fischman, *Forestry*, *in* STUMBLING TOWARD SUSTAINABILITY 327, 331 (John C. Dernbach ed., 2002).
[198] Adger et al., *supra* note 27, at 1037.

the time? The regulatory pitfall, of course, is the muddling of causation: did a species collapse in one area because of overharvest or because of climate change? Given that we are dealing with complex adaptive systems, the answer is likely to be that climate change impacts and human extraction will interact synergistically to produce ecological results that neither would have produced on its own.

Given past failures and these new uncertainties in defining sustainability, climate change adaptation law should promote increased resilience by reenvisioning "sustained yield" and "sustainable yield" management directives to something far more precautionary than has been employed in the past. For example, more protective standards might become more likely, and burdens on public lands managers already struggling with ambiguous definitions of "sustainable yield" perhaps reduced, if natural resources laws presumed that all take, harvest, or extraction in the climate change era is unsustainable until proven otherwise, shifting the burden of proof for appropriate standards to those who wish to take natural resources for their own profit. Similarly, instead of seeking "maximum" and "high-level" sustainable yields, law- and policymakers should consider the alternative of "clearly sustainable" standards that require incorporation of projected climate change impacts and modeling, with revisions as better information becomes available.

Political resistance to these changes is inevitable. Almost by definition, the species subject to sustainable yield standards are economically valuable — worth the time and investment to catch, cut, or harvest. For precisely that reason, however, these are species for which interested parties should want to significantly improve resilience and long-term survival, especially if climate change is already affecting the species' availability. Properly cabined, therefore, existing profit motives and self-interest could provide political palatability for legal reforms.

3. *Stop Subsidizing or Otherwise Encouraging Maladaptive Behaviors, and Provide Incentives for Adaptive Behaviors*

As part of efforts to increase resilience, governments should carefully reevaluate the incentives that laws currently create. Perverse incentives are a recognized if generally unintended consequence of environmental and natural resources law. The CAA's new source review provisions, designed to ensure that existing emitters upgrade their pollution control technology as they upgrade other aspects of the facilities, have instead motivated owners to extend the working life of the facility at less stringent emissions requirements.[199] The ESA's connection of habitat modification to species protection can encourage landowners to destroy protected species before the FWS

[199] Jonathan Remy Nash & Richard L. Revesz, *Grandfathering and Environmental Regulation: The Law and Economics of New Source Review*, 101 Nw. U. L. Rev. 1677, 1713–14 (2007).

knows that they are present.[200] Agencies and legislatures should eliminate these known perverse incentives as part of efforts to increase adaptive capacity.

Additionally, employing existing environmental and natural resources laws in a world of climate change is likely to illuminate other maladaptive incentives not yet obvious. Regulators and legislatures should be alert to such problems and willing to realign incentives when they become apparent.[201]

The laws governing agriculture are a particularly significant source of perverse incentives that climate change adaptation law should address. As Craig Cox has noted, "The environmental implications of U.S. agricultural conservation policy, programs, and institutions are enormous. Cropland, pasture, and rangeland make up more than 50 percent of the land area in the continental United States."[202]

As just one example, subsidies and market realities have encouraged widespread monocropping in both agriculture[203] and forestry, undermining crop species' abilities to cope with new pests and diseases. One result, aided by warm winters, has been the pine beetle's spread through large stands of lodgepole pine in Canada. Another has been increased use of pesticides and

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[200] Stephen J. Dubner & Steven D. Levitt, *Unintended Consequences: The Case of the Red-Cockaded Woodpecker*, N.Y. TIMES MAG., Jan. 20, 2008, at 18–19.

[201] With respect to sea-level rise, for example, Jim Titus has provided a fairly comprehensive overview of how governments, especially the federal government, can change the incentive structures of their various coastal-related programs and laws. *See* James G. Titus, *Does the U.S. Government Realize that the Sea Is Rising? How to Restructure Federal Programs so that Wetlands and Beaches Survive*, 30 GOLDEN GATE U. L. REV. 717, 734–39, 752–71 (2000).

An example of an incentive problem in environmental law that already has largely been realigned to increase adaptive capacity is the problem of ownership of contaminated sites and brownfields under CERCLA. CERCLA's strict, retroactive, and joint and several liability made ownership of contaminated properties financially risky for both lenders and prospective purchasers, even when they clearly bore no responsibility for that contamination. As a result, CERCLA liability obstructed transactions that might otherwise have led to the cleanup and redevelopment of such properties and instead promoted the development (and potential contamination) of "greenfield" sites. Juha Siikamäki & Kris Wernstedt, *Turning Brownfields into Greenspaces: Examining Incentives and Barriers to Revitalization*, 33 J. HEALTH POL. POL'Y & L. 559, 561 (2008). Such perverse incentives applied even to lightly contaminated industrial properties ("brownfields") destined for the foreseeable future for industrial use. *Id.* at 561–62. Through a series of amendments to CERCLA, Congress provided reasonable protections to lenders, 42 U.S.C. § 9601(20)(E) (2006), and made it easier for "bona fide prospective purchasers" to purchase and redevelop "brownfield sites," *id.* §§ 9601(35), 9601(39), 9607(b)(3). While these amendments have not yet perfectly realigned incentives to make redevelopment of contaminated sites the clearly more attractive option to developing "virgin sites," they have nevertheless removed many barriers to reusing contaminated sites. *See, e.g.*, Siikamäki & Wernstedt, *supra*, at 586 (noting that the fact of contamination continues to impede conversion of brownfields to greenspace).

[202] Craig Cox, *U.S. Agriculture Conservation Policy & Programs: History, Trends, and Implications*, *in* U.S. AGRICULTURAL POLICY AND THE 2007 FARM BILL 113, 113 (Kaush Arha et al. eds., 2007).

[203] *See, e.g.*, William S. Eubanks II, *The Sustainable Farm Bill: A Proposal for Permanent Environmental Change*, 39 Envtl. L. Rep. (Envtl. Law Inst.) 10,493, 10,494–95 (2009).

fertilizers,[204] many of which derive from petroleum and hence contribute to our dependence on fossil fuels and to increased greenhouse gas emissions. Moreover, these pesticides and fertilizers become sources of surface and groundwater pollution,[205] stressing downstream aquatic ecosystems such as coral reefs and jeopardizing water supplies. While successive Farm Bills have incorporated incentives for farmers to protect water quality,[206] this legislation has also been much criticized[207] — and incentives on the back end do little to address the core sources of the problem.[208]

As another example, biofuels subsidies have created multiple perverse incentives in the agricultural sector. These subsidies incentivize farmers to convert food crops to fuel crops during a period of worldwide crop failure; to switch to more pesticide- and fertilizer-intensive crops, increasing demand for and application of those products; and to take farmlands out of conservation programs,[209] reducing habitat[210] and increasing threats to water quality.

In contrast, a host of agricultural techniques already exist that would better promote resiliency of crops, agricultural lands, and affected terrestrial and aquatic ecosystems. These include precision farming, organic farming, companion planting and crop rotation, no-till agriculture, buffers in riparian zones, and the cultivation of heirloom species.[211] Rebecca Goldman, Barton

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[204] Rebecca L. Goldman, Barton H. Thompson & Gretchen C. Daily, *Managing for Ecosystems Services on U.S. Agricultural Lands*, *in* U.S. AGRICULTURAL POLICY AND THE 2007 FARM BILL, *supra* note 202, at 97, 99 ("Pesticide use more than doubled in just over 30 years on about 70 percent of current cropland acreage," and "[c]ommercial fertilizers are prevalent on many U.S. farms. In just over 20 years, nitrogen fertilizer use increased 335 percent; over 12 million nutrient tons were being used in 1998.").

[205] *Id.* at 100.

[206] *See* Cox, *supra* note 202, at 115–21 (providing a history of farm environmental programs).

[207] *See, e.g.*, Jonathan Cannon, *A Bargain for Clean Water*, 17 N.Y.U. ENVTL. L.J. 608, 626–27 (2008) (acknowledging that Farm Bill subsidies can themselves create perverse incentives); Cox, *supra* note 202, at 113 (noting that the 2002 Farm Bill spent $4 billion per year on conservation programs but provided crop and farm income subsidies of between $10 and $20 billion per year); Kaush Arha et al., *Conserving Ecosystem Services Across Agrarian Landscapes*, *in* U.S. AGRICULTURAL POLICY AND THE 2007 FARM BILL, *supra* note 202, at 207, 208 (noting that "the present set of farm conservation programs — though successful in part — fails to articulate and execute a conservation strategy that accounts for the full range of ecosystem services across all agricultural landscapes").

[208] Daniel A. Sumner, Kaush Arha & Tim Josling, *Commodity Policy and the 2007 Farm Bill*, *in* U.S. AGRICULTURAL POLICY AND THE 2007 FARM BILL, *supra* note 202, at 5, 14 ("At best commodity programs can be configured to contribute less environmental damage. But it takes other types of programs — those tied directly to environmental outcomes, not those tied to commodity production — to effectively deal with the rural environment.").

[209] *See* Cox, *supra* note 202, at 133 (noting the importance of more permanent land reserves and the great vulnerability of such land reserves to "changes in market conditions, budget pressures, and policy priorities").

[210] *Id.* at 127 (noting that the Conservation Reserve Program in particular had "produced great benefits to wildlife populations — particularly grassland nesting birds and migratory waterfowl").

[211] *See, e.g.*, Goldman et al., *supra* note 204, at 98–100, 106 (discussing precision farming, organic farming, no-till, crop rotation techniques, and means of reducing water pollution in the U.S.).

H. Thompson, and Gretchen C. Daily have recently advocated for "ecological agriculture" to support biodiversity and ecosystem services, including "broad scale landscape vision and management" and "[r]ewards for services rather than just food and fiber."[212] In addition to reducing or eliminating the perverse incentives discussed above, such revised agriculture policies could also promote farms' abilities to provide many ecosystem services that would contribute both to the productivity of the farmland itself and to the resiliency of socio-ecological systems, including water purification, pollination, soil fertility, sequestration of greenhouse gases, flood mitigation, and biodiversity enhancement.[213] Reworking[214] and rescaling[215] the legal incentives for agriculture thus could yield widespread benefits by increasing the resilience and adaptive capacity of many sectors and ecosystems.

Although not directly a component of environmental regulation and natural resource management, insurance also provides important incentives relevant to both mitigation and adaptation law.[216] In particular, government-subsidized insurance programs can provide either adaptive or maladaptive incentives to insured parties. The National Flood Insurance Program, for example, has already been widely criticized for the incentives it provides property owners to develop and rebuild in floodplains and along coasts.[217] This is a highly maladaptive incentive in the face of projected increased flooding, coastal storms, and rising sea levels.

4. *Preserve and Expand Open Space and Ecosystem Connectivity*

As noted, climate change is likely to outstrip, or at the very least challenge, species' and ecosystems' intrinsic capacities to adapt, even if those capacities are not already diminished by anthropogenic stressors. As the IPCC noted in 2007, one of the potential barriers to climate change adaptation is "the inability of natural systems to adapt to the rate and magnitude of climate change."[218] Given that one of the most damaging existing stressors

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[212] *Id.* at 97; *see also* Arha et al., *supra* note 207, at 207 (arguing that "conserving ecosystem services across the agrarian landscapes should deservedly be recognized as one of the major goals of the U.S. agricultural policy").

[213] Goldman et al., *supra* note 204, at 100–05, 106–07.

[214] *See, e.g.*, Cox, *supra* note 202, at 129 (advocating that the U.S. "[r]etool conservation programs and institutions for environmental management and enhance the environmental performance of the conservation programs we already have in place" and provide "'[g]reen' crop subsidy, insurance, and related programs designed to support income, stabilize price, or manage risk").

[215] *See, e.g.*, *id.* at 131 (advocating a change in focus from individual farms to the watershed or landscape scale); Goldman et al., *supra* note 204, at 107 (noting that managing agriculture for certain ecosystem services, such as flood mitigation, biodiversity conservation, and water quality requires "looking at the agricultural system as a landscape").

[216] *See, e.g.*, Sean B. Hecht, *Climate Change and the Transformation of Risk: Insurance Matters*, 55 UCLA L. Rev. 1559 (2008).

[217] *See, e.g.*, Jim Blackburn & Larry Dunbar, *Houston's High Water Problems*, 46 Houston Lawyer 18, 22–23 (2008); Kelley M. Jancaitis, *Florida on the Coast of Climate Change: Responding to Rising Seas*, 31 Environs: Envtl. L. & Pol'y 157, 186 (2008).

[218] IPCC, Adaptation Report, *supra* note 7, at 719.

for many species is loss of habitat,[219] one of the most effective adaptation measures humans could implement may be to preserve as much connected and varied open space as is physically and politically possible and let species and ecosystems sort themselves out in response to climate change impacts.[220]

Lending support to this subprinciple, the USCCSP has suggested that coastal management programs that already preserve open space along the coast "may also help coastal ecosystems adapt to rising sea level,"[221] recognizing that, "[u]nder natural conditions, habitats are continually shifting, and species generally have some flexibility to adapt to varied geography and/or habitat type."[222] Jonathan Verschuuren at Tilburg University, the Netherlands, has recommended an adaptation strategy focused on "making protected areas climate proof by making sure that these areas are large enough and stable enough to adapt to the changed climate":

> Protected areas should be able to live through flooding in winter, wild fires in the summer, [and] storm damage and should have enough variety in habitat types to host new species. This for many protected areas means an enormously intensified protection measures [sic], for instance by enlarging sites or connecting existing sites into one much larger site.[223]

Similarly, seventeen marine scientists have declared that networks of no-take marine reserves and better management of the areas surrounding them are "essential" to coral reef resilience and survival in an era of climate change.[224]

Assisted migration for species is a much-debated adaptation strategy that might limit the need for additional protected areas.[225] While acknowl-

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[219] Eric W. Seabloom, Andy P. Dobson & David M. Stoms, *Extinction Rates Under Nonrandom Patterns of Habitat Loss*, 99 PROC. NAT'L ACAD. SCI. 11,229, 11,229 (2002).

[220] *See* Zinn, *supra* note 56, at 87–88 (describing the potential "death by a thousand cuts" from habitat loss).

[221] U.S. CLIMATE CHANGE SCI. PROGRAM, SYNTHESIS AND ASSESSMENT PRODUCT 4.1: COASTAL SENSITIVITY TO SEA LEVEL RISE: A FOCUS ON THE MID-ATLANTIC REGION 6 (2009).

[222] *Id.* at 5.

[223] Verschuuren, *supra* note 45, at 6. *See also* Adger et al., *supra* note 27, at 1037 ("Spatial heterogeneity can also confer resilience . . . ."); CALDECOTT, *supra* note 58, at 204–05 (describing the importance of expanding protected areas, while simultaneously emphasizing that non-protected areas are not then "expendable").

[224] Hughes et al., *supra* note 153, at 932. *See also* Moises Velasquez-Manoff, *Parks That Can Move When the Animals Do*, CHRISTIAN SCI. MONITOR, Mar. 4, 2009, at 13 ("[F]ew — and maybe none — of the more than 4,500 marine protected areas (MPAs) established worldwide have been explicitly designed to cope with climate change . . . [but experts] are already thinking about how to design MPAs that still function as climates change. Maybe they're bigger, say scientists, or spaced like stepping stones . . . . Perhaps they're not tied to a geographic location at all . . . .").

[225] *See, e.g.*, Julie Lurman Joly & Nell Fuller, *Advising Noah: A Legal Analysis of Assisted Migration*, 39 Envtl. L. Rep. (Envtl. Law Inst.) 10,413 (2009); Glicksman, *supra* note 140, at 889–91; John Kostyack & Dan Rohlf, *Conserving Endangered Species in an Era of Global Warming*, 38 Envtl. L. Rep. (Envtl. Law Inst.) 10,203, 10,209 (2008); Ruhl, *Building Bridges*, *supra* note 112, at 53, 61–62; Jason S. McLachlan et al., *A Framework for Debate of Assisted Migration in an Era of Climate Change*, 21 CONSERVATION BIOLOGY 297, 298–99 (2007).

edging that debate and the potential value of assisted migration in certain circumstances — as well as the probable necessity for seed banks, botanic gardens, and zoos as stopgap measures to save otherwise doomed species — this Article consciously adopts an attitude of humility in the face of ecological responses to climate change and assumes that, given enough room and enough options, Nature will generally do a better job of adapting ecosystems to new baseline conditions than humans will. As the IPCC has pointed out, "Human intervention to manage the process of adaptation in biological systems is also not well understood, and the goals of conservation are contested."[226]

Hobbs and Cramer acknowledge that the new reality of climate change adaptation and the "no-analogue future" suggest the need "for a new approach in which ecological restoration focuses on the future as much as, if not more than, on the past" and that "the pathway toward this new formulation is not yet clear and requires new ways of thinking and clearer insights regarding the dynamics of ecosystems under novel conditions."[227] As a result, "it remains important to question the extent to which humanity can meddle with nature, albeit in an increasingly intelligent way, given the legacy of problems from past attempts."[228]

Principle #3: Plan for the Long Term with Much Increased Coordination Across Media, Sectors, Interests, and Governments

As decision makers acquire reliable information about local and regional climate change impacts, planning for future climate change adaptation will become increasingly important at all levels of government.[229]

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[226] IPCC, Adaptation Report, *supra* note 7, at 737. More generally, humans' ability to restore ecosystems has been limited, even in contexts where we have a good idea of what's missing or what went wrong; what restoration abilities exist are likely to be substantially reduced as the ecosystems themselves reshuffle components. As restoration ecologists Richard Hobbs and Viki Cramer have noted, however, "[d]eciding on what type of intervention, if any, is required for the effective restoration of an ecosystem (or particular components or processes) presupposes a clear understanding of how the ecosystem works and what the outcomes of the intervention are likely to be." Hobbs & Cramer, *supra* note 121, at 42. Furthermore, "[t]he more degraded an ecosystem is, and the more fundamentally the basic ecosystem processes have been altered, the more difficult and expensive restoration will be." *Id.* at 43. Thus, Hobbs and Cramer recently summarized, "[i]t is becoming increasingly apparent that the theoretical and practical underpinnings of restoration have to be reconsidered in the light of rapid environmental changes, which can act synergistically to transform ecosystems and render the likelihood of returning to past states more unlikely." *Id.* at 50.

[227] *Id.* at 51.

[228] *Id.* at 54–55.

[229] Heltberg and fellow researchers concluded that:

> [W]hile most adaptation will necessarily take place at the local level, global efforts are required. What we mean is that most successful adaptation efforts are likely to be local as communities and other subnational actors respond to the localized manifestations of emerging climate risks. However, local actors will increasingly need external support because the risks — large, covariate, and possibly with irreversible damages — can overwhelm local adaptive capacity.

However, to reduce redundancies, increase efficiency, and avoid conflicting adaptation measures, planning must be coordinated, and where possible integrated, within and among those various levels. Thus, Principle #3 calls for planning that is both longer term and better coordinated than what currently exists, with adjustments to relevant institutional structures as necessary.

Adaptation measures can be classified along a number of variables, but two of the most important for law and planning are the temporal variable and the spatial scale variable. With respect to temporal variability, regulatory adaptation efforts can respond to three basic and overlapping levels of climate change effects: current variability; medium- and long-term trends that have actually been observed in the relevant locality; and predicted longer-term changes based on modeling.[230] Measures that respond to current variability — observed changes — are often the most politically palatable because they address acknowledged and often relatively limited changes in circumstances.[231] Regulation to adapt to longer-term and especially predicted changes may be prudent in the long run,[232] but it is also far more likely to raise political obstacles as a result of greater uncertainties in the effects, greater immediate costs to implement, potentially greater displacement from the status quo, and the frequent mismatch of ecological and political timescales. Thus, climate change adaptation law must have mechanisms that both allow for and encourage adaptation planning and implementation of adaptation measures on a variety of timescales.

The spatial scale variable acknowledges that climate change impacts, and the means of adapting to them, can occur at several spatial scales. For example, the decreasing ability of Delta smelt to survive in the Sacramento–San Joaquin Delta or of farmers in Montana to have adequate water supplies for summer irrigation are fairly local effects, while the pine beetle infestation is an impact of national importance, and the conversion of Arctic tundra to Arctic shrubland is a change of regional and arguably international scale. Complicating the legal aspects of this spatial dimension is the fact that laws potentially applicable to any one of these impacts can exist at several levels of government simultaneously, leading to potential fragmentation of regulatory purpose.[233] Laws relevant to the Delta smelt and Montana's rivers, for example, include city or county land use planning requirements, state water law and environmental policies, state-federal interactions such as contracts governing irrigation projects or cooperative federalism arrangements under the CWA or CAA,[234] and purely federal regulation, as through the ESA.[235] Coordinating levels of regulation to generate appropriate adap-

Heltberg et al., *supra* note 27, at 95.

[230] IPCC, ADAPTATION REPORT, *supra* note 7, at 720.

[231] *See id.* at 720–21 (discussing such measures as promoting existing development goals).

[232] *Id.* at 721.

[233] *See generally* Craig, *supra* note 115 (discussing the regulatory problems of protecting coastal estuaries and the probability that climate change will make regulatory coordination even more difficult).

[234] 33 U.S.C. § 1342(b) (2006).

[235] 16 U.S.C. §§ 1536, 1538 (2006).

tive responses at the relevant spatial scale is one of the great challenges for the law of climate change adaptation.[236]

The subprinciples in this section offer initial suggestions for acknowledging and effectively incorporating these multi-scalar aspects of climate change adaptation.

1. *Acknowledge and Avoid Potential Conflicts Between Human and Species/Ecosystem Adaptation*

As the IPCC pointed out in 2007, most of the literature regarding socio-ecological systems' responses to climate change has focused on the limitations that ecological changes may impose on humans' capacities to adapt.[237] In a particularly dramatic example of this perspective, researchers at the World Bank recently argued "that serious — even catastrophic and irreversible — damage to natural systems from climate change need not result in catastrophic and irreversible damage to humans. In contrast, catastrophic and irreversible damage to humans can result even from modest changes in natural systems."[238]

In contrast to this anthropocentric point of view, not enough attention has been paid to the fact that reverse influences are also likely — that is, that human adaptations to climate change will interfere with species' and ecosystems' capacities to adapt.[239] For example, coastal populations in the United States may start moving inland in response to rising sea levels, building new homes and businesses on previously undeveloped land and almost certainly putting additional stress on the species trying to survive in those same spaces. Californians and other residents of an increasingly water-strapped West may migrate in mass numbers to wetter areas, shifting their demand to new water resources.

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[236] *See generally* Craig, *supra* note 115; Ruhl & Salzman, *supra* note 84 (creating a typology of various kinds of "wicked" regulatory problems and suggesting strategies for regulatory agencies in addressing them); Hari M. Osofsky, *Is Climate Change "International"? Litigation's Diagonal Regulatory Role*, 49 VA. J. INT'L L. 587, 587 (2009) (noting that "[c]limate change is an individual, local, state, national, regional, and international problem" and proposing the concept of "diagonal regulation" as a means of coordinating these various regulatory spheres). My thinking on the spatial and governance issues involved in climate change has benefited greatly from conversations and correspondence with Alex Camacho, Hari Osofsky, and J.B. Ruhl, and I thank them for that engagement.

[237] IPCC, ADAPTATION REPORT, *supra* note 7, at 734; *see* Ford, *supra* note 25; Farber, *supra* note 33, at 1394 ("Adaptation planning requires an assessment of how climate will impact human activities and how to respond to those changes."); *World's Fisheries Face Climate Change Threat*, ENVTL. NEWS NETWORK, Feb. 23, 2009, http://www.enn.com/top_stories/article/39359 (on file with the Harvard Law School Library) (warning "that millions of people dependent on fisheries in Africa, Asia and South America could face unprecedented hardship as a consequence of climate change").

[238] Heltberg et al., *supra* note 27, at 89.

[239] *See* Zinn, *supra* note 56, at 66 ("The direct environmental changes caused by unabated climatic warming will put new pressure on human communities to which they will need to adapt, either proactively or retroactively. In turn, those adaptations will produce secondary environmental effects scarcely discussed in the climate change literature."); *id.* at 67–81 (describing a variety of these secondary impacts).

In contrast to human efforts to adapt to climate change, biological adaptation — the adaptation of species and ecosystems — is purely reactive, not anticipatory.[240] Thus, humans should do the anticipating and provide other species with space to adapt, underscoring both the need for comprehensive adaptation planning and the importance of Subprinciple 4 of Principle #2.

The litigation that has required federal agencies to consider climate change impacts as part of their existing assessment duties under NEPA and Section 7 of the ESA provides one step toward incorporating this subprinciple into law.[241] Indeed, in June 2009, in a Section 7 Biological Opinion, NMFS actively incorporated climate change impacts into its description of the ecological baseline for six ESA-listed species potentially affected by the Central Valley Project/State Water Project in California.[242] It concluded that "[t]he historic hydrologic pattern . . . can no longer be solely relied upon to forecast the future" and that "[c]limate change will affect the entire life cycle of salmonids and sturgeon through warmer ocean periods, changes in age and size at maturity, decline in prespawn survival and fertility due to higher stream temperatures, and a loss of lower elevation habitat."[243] Models and the latest scientific information "indicate[ ] that climate change will negatively affect the Central Valley listed species and their proposed or designated critical habitats."[244] As a result, NMFS incorporated anticipated climate change impacts into its "Reasonable and Prudent Alternatives" recommendations.[245]

States are also beginning to anticipate the need to accommodate wildlife in human adaptation. In June 2008, the Western Governors' Association established the Western Wildlife Habitat Council.[246] Among other duties, the Council is tasked to "[c]oordinate and implement steps that foster establishment of a 'Decisional Support System' (DSS) with each state," including "[p]rioritization of the process for identifying wildlife corridors and crucial habitats, and taking steps accordingly to support adaptation to climate change."[247] The Council is also working "to establish policies that ensure information from state-led Decisional Support Systems is considered early in planning and decision-making processes, whether federal, tribal, state or local, in order to preserve these sensitive landscapes through avoidance, minimization, and mitigation."[248]

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[240] IPCC, ADAPTATION REPORT, *supra* note 7, at 720.

[241] *But see* Zinn, *supra* note 56, at 85 (questioning the efficacy of the NEPA EIS for climate change adaptation).

[242] NMFS, CVP/SWP OPINION, *supra* note 12, at 172–74.

[243] *Id.* at 173 (citation omitted).

[244] *Id.* However, NMFS also noted that "[u]ncertainties abound at all levels. We have only the crudest understanding of how salmonid habitats will change and how salmonid populations will respond to those changes, given a certain climate scenario." *Id.*

[245] *Id.* at 579.

[246] W. GOVERNORS' ASS'N, *supra* note 168, at 1.

[247] *Id.* at 2. *See also id.* at 5 (detailing climate change impacts to wildlife in the context of other anthropogenic impacts).

[248] *Id.* at 2.

Acknowledging the coadaptation of species and ecosystems with humans has obvious implications for land use planning, growth management, and agriculture law, as well. For example, efforts to apply this subprinciple may create yet another incentive to incorporate New Urbanism approaches to city planning, concentrating human settlements into densely settled and self-sufficient neighborhoods and towns, with limited connections between such neighborhoods and towns.[249] Such a strategy could simultaneously increase humans' adaptive capacity by reducing energy consumption and demand and improving human health.[250]

However, this subprinciple may also challenge policy makers' assumptions about the scales of planning relevant to climate change adaptation.[251] Local land use planning, for example, operates at the wrong scale to deal with mass migrations. Moreover, the potential for mass migrations may create a demand for national-level cost-benefit analyses of adaptation strategies and lead to changes in assumptions about who controls what resources. For example, despite the general presumption that water law and water allocation are state prerogatives, it may be that, at the national level, everyone is better off if the nation as a whole finds ways to reliably supply California's almost thirty-four million people with sufficient water, and hence encourage them to remain in California cities, rather than do nothing and experience a reverse–Dust Bowl mass migration to relatively unsettled plains regions.

2. *Acknowledge Climate Change in All Levels of Governmental Planning*

Despite the potential for climate change to impact water resources, agricultural productivity, forest productivity, and coastal management, climate change considerations have yet to be widely incorporated into governmental planning and assessment at any level.[252] As the IPCC recognized in 2007,

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[249] For information about New Urbanism, see generally Online NewsHour, *New Urbanism: What Is New Urbanism?*, http://www.pbs.org/newshour/newurbanism/keypoints.html (last visited Dec. 27, 2009) (on file with the Harvard Law School Library).

[250] *See* New Urbanism, Sprawl and Health, http://www.newurbanism.org/newurbanism/sprawlhealth.html (last visited Dec. 27, 2009) (on file with the Harvard Law School Library); New Urbanism, Green Transportation, http://www.newurbanism.org/transport.html (last visited Dec. 27, 2009) (on file with the Harvard Law School Library) (noting that employment of these principles leads to less dependence on cars and foreign oil).

[251] For example, Emma Tompkins and Neil Adger have argued that:

> [T]he imposed impacts of climate change are manifest at particular localities. In some political systems, although the appropriate institutional scale for adaptation is often that of municipal or local resource management institutions, the interaction between institutions across scales is constrained by the power relationships among these bodies. In effect, the diversity of impacts of climate change means that the most appropriate adaptation responses will often be on multiple levels.

Tompkins & Adger, *supra* note 66, at 3 (citation omitted).

[252] *See, e.g.*, Glicksman, *supra* note 140, at 866–68 (recommending that the federal public lands agencies "make climate change a priority in the planning process").

such planning is critical.[253] Moreover, the IPCC labels this integration of climate change planning into existing regulatory programs and structures as "mainstreaming," and it considers mainstreaming important for all levels of government, from the international to the local.[254]

In general, "mainstreaming" refers to the incorporation and prioritization of climate change adaptation considerations into all areas of government regulation and planning for development.[255] Mainstreaming thus prevents climate change adaptation from being relegated to an afterthought and instead integrates adaptation considerations into existing procedures and decision making. In Least Developed Countries, for example, mainstreaming generally requires that climate change adaptation be incorporated "within the national policy making processes in those countries."[256]

In the United States, New York City provides one fairly comprehensive example of climate change mainstreaming at the municipal level. The City has adopted a Climate Change Initiative, a strategy that addresses land, water, transportation, energy, and air issues.[257] Indeed, the climate change strategy "is the sum of all the initiatives in this plan."[258] While the City focused first on climate change mitigation and reducing its greenhouse gas emissions, it is now beginning "a long-term effort to develop a comprehensive climate change adaptation strategy, to prepare New York for the climate shifts that are already unavoidable."[259] Such comprehensive mainstreaming needs to occur in all governments in the United States — local, state, and federal.

3. *Consider a Range of Possible Long-Term Futures When Planning*

The IPCC has emphasized that the effects of climate change on human society depend significantly on which development pathway individual societies and the world at large decide to follow.[260] Because many of these decisions are currently outside of any one government's complete control, planners need to consider a range of potential future events and ecological states. In addition, the unpredictability of climate change effects and especially of those impacts' interactions and feedback loops counsels governments and other decision makers to consider a wide range of possible futures

[253] IPCC, ADAPTATION REPORT: SUMMARY FOR POLICYMAKERS, *supra* note 57, at 20.
[254] *Id.* at 731–33.
[255] *See* ORGANISATION FOR ECON. CO-OPERATION & DEV., POLICY BRIEF: PUTTING CLIMATE CHANGE ADAPTATION IN THE DEVELOPMENT MAINSTREAM 1 (2006), *available at* http://www.oecd.org/dataoecd/57/55/36324726.pdf (indicating that mainstreaming works to "[b]ridg[e] the gap between the climate change adaptation and development communities").
[256] SALEEMUL HAQ ET AL., MAINSTREAMING ADAPTATION TO CLIMATE CHANGE IN LEAST DEVELOPED COUNTRIES (LDCS) 7 (2003), *available at* http://www.un.org/special-rep/ohrlls/ldc/LDCsreport.pdf.
[257] PLANYC, *Climate Change*, http://nyc.gov/html/planyc2030/html/plan/climate.shtml (last visited Dec. 27, 2009) (on file with the Harvard Law School Library).
[258] *Id.*
[259] *Id.*
[260] HAQ ET AL., *supra* note 256, at 19–20.

when planning adaptation strategies, especially over the longer term. Daniel Farber has emphasized this point recently, arguing that "[r]ather than searching for economically efficient strategies to address climate change, we should focus . . . on adaptation strategies that are robust across a broad range of scenarios."[261]

To find such robust strategies, however, planners must first describe and incorporate a broad range of potential futures. As the IPCC acknowledged in 2007, "climate change poses novel risks often outside the range of experience, such as impacts related to drought, heatwaves, accelerated glacier retreat and hurricane intensity."[262]

Thus, an important tool for adaptation planning will be scenario building. Scenario building aids long-term planning by considering multiple plausible futures, without predicting the "most likely" future conditions.[263] Instead, the goal of scenario building is to "challenge assumptions and foster strategic thinking about possible responses to different futures."[264] The National Park Service, for example, is already using scenario building to plan for climate change.[265] Ideally, climate change adaptation scenario building would make use of the information gathered and models produced in pursuit of Principle #1.

4. *Increase Regulatory Coordination Across Media and Objects*

American environmental and natural resources law tends to create different regulatory regimes for different media and regulatory objects, with limited requirements for coordination among those regimes. With respect to pollution regulation, for example, federal law creates the CAA, the CWA, and, for land, RCRA and CERCLA. Forests are managed under different statutes than other public lands, while endangered species, migratory birds, fish, and marine mammals each have their own governing federal statutes.

Links between such statutes are limited, leaving certain problems unresolved. For example, mercury emitted into the air by sources regulated under the CAA falls out of the sky, often making its way into bodies of water.[266] Nevertheless, the CAA's emission requirements for mercury do not require EPA to set emissions standards sufficient to prevent water pollution.[267]

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[261] Farber, *supra* note 33, at 1357.

[262] IPCC, ADAPTATION REPORT, *supra* note 7, at 719.

[263] Leigh Welling, *Climate Change Scenario Planning: A Tool for Managing Resources in an Era of Uncertainty* 3 (2008), *available at* http://www.fs.fed.us/psw/cirmount/meetings/mtnclim/2008/talks/pdf/Welling_Talk2008.pdf (on file with the Harvard Law School Library).

[264] *Id.* at 4.

[265] *See generally id. See also* W. GOVERNORS' ASS'N, *supra* note 168, at 30 (recommending changes in wildlife corridor planning accounting for projected climate change impacts).

[266] Craig, *supra* note 115, at 857–61, 885–87.

[267] 42 U.S.C. § 7412(d)(2) (2006) (requiring only that the EPA Administrator "tak[e] into consideration . . . any non-air quality health and environmental impacts," among other factors, when setting the technology-based National Emissions Standards for Hazardous Air Pollution).

Climate change adaptation law needs to recognize and fill the gaps between existing regulatory regimes to ensure that regulation under one law does not undermine the resilience and adaptive capacity of another medium or regulatory object. For pollution control statutes, such coordination can most easily be incorporated into the existing regulation of the source. In natural resource management, coordination may more often require legislatures to decide which management regime takes priority and then require overlapping regimes to acknowledge that priority. For example, Congress has coordinated certain aspects of endangered species and marine mammal regulation so that endangered or threatened marine mammals receive the most stringent of the protections that either the ESA or the Marine Mammal Protection Act offers them.[268]

5. *Increase Regulatory Coordination Among Governmental Bodies*

According to the IPCC, responses to climate change should include "actions at all levels from the individual citizen through to national governments and international organizations."[269] Such multilevel efforts, however, will be most effective if they are coordinated or, at the very least, not working at cross-purposes.

Regulatory fragmentation, however, is a prominent feature of environmental and natural resources law, interfering with government coordination toward a common goal of increasing resilience and adaptive capacity.[270] Celebrating the fact that states and the federal government operate in overlapping, rather than distinct, spheres of regulatory authority, the expanding literature of dynamic federalism is already suggesting new productive possibilities for the interactions of those two levels of government.[271] These explorations may bear fruit for climate change adaptation law.[272]

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[268] 16 U.S.C. § 1536(b)(4)(C) (2006).

[269] IPCC, ADAPTATION REPORT: SUMMARY FOR POLICYMAKERS, *supra* note 57, at 20.

[270] Glicksman, *supra* note 140, at 873–75; Craig, *supra* note 115, at 834–61, 866–78, 884–90; Zinn, *supra* note 56, at 83, 86–87; William W. Buzbee, *Recognizing the Regulatory Commons: A Theory of Regulatory Gaps*, 89 IOWA L. REV. 1, 27–36 (2003). As the Western Governors' Association concluded:

> Wildlife do not observe political boundaries or land ownership. Conservation of wildlife corridors and crucial habitats must therefore be coordinated across government, including the federal land management agencies (BLM & Forest Service), federal agencies responsible for water delivery and flood control (Bureau of Reclamation and the Corps of Engineers), federal wildlife agencies (Fish and Wildlife Service and [NMFS]), tribal governments, states; and local governments.

W. GOVERNORS' ASS'N, *supra* note 168, at 6.

[271] *See, e.g.*, David E. Adelman & Kirsten H. Engel, *Adaptive Federalism: The Case Against Reallocating Environmental Regulatory Authority*, 92 MINN. L. REV. 1796, 1799–1802 (2008) (arguing for an ecosystem-like model of adaptive federalism in environmental law); Kirsten H. Engel, *Harnessing the Benefits of Dynamic Federalism in Environmental Law*, 56 EMORY L.J. 159, 174–77 (2006) (arguing that the old model of dual federalism is not the reality in environmental law and extolling the benefits of dynamic federalism).

[272] Scholars are certainly already considering its benefits for climate change mitigation. *See, e.g.*, Daniel P. Schramm, *A Federal Midwife: Assisting the States in the Birth of a Na-*

Other mechanisms are also likely to be helpful. For example, overcoming regulatory fragmentation may require legislatures to align and prioritize statutory mandates. In addition, new coordinating bodies may prove helpful in avoiding inefficient fragmentation of climate change adaptation efforts. I have suggested elsewhere, for example, that watershed-level entities could provide comprehensive oversight of the various navigation, damming, water allocation, agricultural, pollution regulation, species protection, recreation, estuary, and coastal decisions made within that watershed.[273] Daniel Farber, in turn, has suggested that a new Sustainability Office is needed within the Office of Management and Budget to coordinate the current Office of Information and Regulatory Affairs, the Council on Environmental Quality, and parts of the National Oceanic and Atmospheric Administration and the FWS.[274]

6. *Give Meaningful Weight to Public Rights and Values in Private Property*

As the IPCC has acknowledged, there are significant "financial, cognitive and behavioural, and social and cultural constraints" on the implementation of adaptation measures.[275] In the United States, one source of resistance to significant adaptation measures is likely to be popular conceptions of private property rights as "absolute,"[276] while fear of constitutional "takings" liability is likely to inspire at least some governments to drag their proverbial feet in implementing necessary measures.[277] In addition, as Lawrence Brown and Lawrence Jacobs have noted, American culture has tended to "embrace[ ] minimal government and maximal individual liberty."[278] None of these proclivities are well suited to climate change adaptation, which is likely to require a community-based valuation system.[279] Climate change

tional Greenhouse Gas Cap-and-Trade Program, 22 TUL. ENVTL. L.J. 61, 86 (2008) (extolling the virtues of dynamic federalism in a cap-and-trade program over picking one level of government).

[273] Craig, *supra* note 115, at 925–27.

[274] Farber, *supra* note 33, at 1397–99.

[275] IPCC, ADAPTATION REPORT, *supra* note 7, at 719.

[276] Christine A. Klein, *The New Nuisance: An Antidote to Wetland Loss, Sprawl, and Global Warming*, 48 B.C. L. REV. 1155, 1158–67 (2007).

[277] *See, e.g.*, Darren Botello-Samson, Lawsuits, Property, and the Environment: Measuring the Impact of Regulatory Takings Litigation on Surface Coal Mining Regulations 42–43 (Aug. 31, 2006) (unpublished manuscript), *available at* http://www.allacademic.com/meta/p151975_index.html (suggesting that regulatory takings litigation can have a chilling effect on environmental and natural resources regulation).

[278] BROWN & JACOBS, *supra* note 157, at 128.

[279] Tompkins and Adger write that:

> Although not a panacea, community engagement may offer a means of reducing vulnerability to the natural hazards associated with climate change. Critiques of how participatory planning is applied have highlighted its frequent lack of consideration for ecosystem heterogeneity and intracommunity dynamics as well as the differential access to resources inherent in some community-based management.

Tompkins & Adger, *supra* note 66, at 2 (citations omitted).

adaptation law should thus anticipate the need for several alterations in cultural norms,[280] much as World War II required several layers of pervasive domestic cultural adjustments, including in the workforce, in consumption patterns, and in acceptable and desirable behaviors.

Notably, when the IPCC reported on climate change adaptation measures in the United States, it emphasized state land acquisition programs[281] that facilitate the conversion of private land to public land, which makes the implementation of land-based adaptation measures easier.[282] Moreover, within the United States, the public interest–private rights tug-of-war has been engaged in repeatedly in the context of coastal protection measures; it is no accident that one of the most prominent regulatory takings cases in the U.S. Supreme Court involved restrictions on coastal development.[283]

As Christine Klein has recognized, "[i]n a healthy society, there is a rough give-and-take between individual autonomy and community well-being."[284] In an unhealthy, stressed, or war-ravaged society, in contrast, the balance tends to tip sharply in favor of preservation of the community, allowing for measures such as quarantine, rationing, and the suspension of habeas corpus.

Like war and epidemic diseases, climate change adaptation could well become a matter of community survival. As such, it warrants rebalancing of public and private interests. As this Article has argued throughout, climate change impacts will alter the basic parameters of ecosystems, which in turn provide ecosystem services[285] to human communities, creating complex coupled socio-ecological systems. Climate change threatens to transform these

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[280] *See, e.g.*, *id.* at 10 ("Adaptation to climate change requires a broader conceptualization of equitable, legitimate, and sustainable development in effective and resilient response."); *id.* at 11 ("Action to adapt and maintain resilience in the face of climate change requires adjustments by governments, by individuals acting as citizens and through market exchange, and by civil society through collective action."); *id.* at 12 ("[N]ot all ways of adapting to climate change are in harmony with existing social norms, institutions, and structures.").

[281] IPCC, ADAPTATION REPORT, *supra* note 7, at 722 tbl.17.1. Specifically, the Report highlighted:

> Land acquisition programmes taking account of climate change (e.g., New Jersey Coastal Blue Acres land acquisition programme to acquire coastal lands damaged or prone to damages by storms or buffering other lands; the acquired lands are being used for recreation and conservation); establishment of a 'rolling easement' in Texas, an entitlement to public ownership of property that 'rolls' inland with the coastline as sea-level rises; other coastal policies that encourage coastal landowners to act in ways that anticipate sea-level rise.

Id. See also W. GOVERNORS' ASS'N, *supra* note 168, at 6 ("Wildlife conservation on private lands is best accomplished through the use of incentives and tools that encourage and facilitate private landowners and private industry to achieve conservation objectives.").

[282] *See also* Glicksman, *supra* note 140, at 877–81 (discussing the federal government's potential uses of the Property Clause and condemnation authority to protect public lands and their ecosystems in an era of climate change).

[283] Lucas v. S.C. Coastal Council, 505 U.S. 1003 (1992).

[284] Klein, *supra* note 276, at 1158.

[285] *See generally, e.g.*, NATURE'S SERVICES: SOCIETAL DEPENDENCE ON NATURAL ECOSYSTEMS (Gretchen C. Daily ed., 1997); COMM. ON ASSESSING & VALUING THE SERVS. OF AQUATIC & RELATED TERRESTRIAL ECOSYSTEMS, NAT'L RESEARCH COUNCIL, VALUING

systems, rendering human societies vulnerable. As a legal matter, that threat alone should be sufficient to prompt revitalized legal attention to the public and community values of private property and to the legal doctrines that give cognizance to those values: nuisance,[286] the public trust doctrine,[287] and public necessity.[288]

Principle #4: Promote Principled Flexibility in Regulatory Goals and Natural Resource Management

Given the complex nature of ecosystems, long-term planning, even when based on robust adaptation strategies or better scientific information about climate change impacts, is unlikely to eliminate all surprises. Moreover, climate change adaptation planning and implementation by definition address continual, not one-time, change, and that change will often be nonlinear. Therefore, Principle #4 is to adapt the law itself to allow principled flexibility to become a reality.

1. *Interpret or Amend Existing Laws to Allow Principled Flexibility Regarding Environmental Management Goals to Reflect Changing Baseline Conditions*

Environmental laws, particularly pollution control laws, have often been inflexible in certain respects. For example, anti-backsliding requirements are important components of many pollution control permits.[289] Principled flexibility does not require the elimination of these provisions, particularly where such measures prevent or reduce regulable (non–climate change–caused) anthropogenic stresses in accordance with Subprinciple 1 of Principle #2. Moreover, many existing laws already contain provisions that are sufficiently flexible to address climate change impacts to baseline ecological conditions.[290]

ECOSYSTEM SERVICES: TOWARD BETTER ENVIRONMENTAL DECISION-MAKING (2005); RUHL ET AL., *supra* note 35.

[286] *See, e.g.*, Michael C. Blumm & Lucus Ritchie, Lucas*'s Unlikely Legacy: The Rise of Background Principles as Categorical Takings Defenses*, 29 HARV. ENVTL. L. REV. 321, 331–41 (2005) (describing the role of public nuisance as a limitation on private property rights).

[287] *See, e.g.*, California v. Super. Ct. Placer County, 625 P.2d 256, 260 (Cal. 1981) (upholding the public interest in public trust protections for shore lands and noting that "[p]reservation of the public trust in the shore zone will allow the state the flexibility in determining the appropriate use of such land").

[288] *See, e.g.*, John Alan Cohan, *Private and Public Necessity and the Violation of Property Rights*, 83 N.D. L. REV. 651, 690–733 (2007) (outlining the various kinds of public necessity and the right of public needs to impinge on private property rights and noting that no compensation is required if private property is destroyed to avoid a "public calamity").

[289] *See, e.g.*, 33 U.S.C. § 1342(o) (2006) (providing the CWA's anti-backsliding provision for National Pollutant Discharge Elimination System permits).

[290] *See* Craig, *The Cutting Edge*, *supra* note 148, at 17 (discussing the value of the CWA's water quality criteria and water quality-based effluent limitation provisions for climate change adaptation).

Nevertheless, existing law does occasionally restrict flexibility in ways that could undermine climate change adaptation. For example, the water quality standards provisions of the CWA include an antidegradation requirement, which prohibits states from allowing existing uses of water bodies to degrade.[291] Because water quality standards must incorporate existing uses as designated uses,[292] climate change–driven changes to baseline water conditions can both put a state in violation of the antidegradation policy and, more importantly, trigger the Act's TMDL provisions,[293] designed originally to ensure that waters would eventually meet and maintain the applicable water quality standards.[294]

The TMDL provisions are an important tool for protecting the nation's waters from standard anthropogenic sources of water pollution, and this Article does not advocate their repeal. However, when violations of water quality standards derive solely or most significantly from climate change impacts, restoring pre–climate change water quality is likely to be practically impossible. For example, Montana's streams, pre–climate change, supported healthy trout populations. If climate change impacts continue to raise water temperatures, those existing trout uses may become unsupportable. However, forcing Montana into the expensive and time-consuming process of drafting and implementing a TMDL is sheer waste, because no immediately regulable sources of effluent or runoff can bring stream temperatures back down. Incorporating a "climate change adaptation exemption" into such provisions would avoid inefficient and expensive inflexibility in the face of climate change impacts that alter baseline ecological conditions.

Of course, increasing regulatory flexibility always opens the door to potential abuse.[295] However, there are ways to cabin climate change adaptation exemptions to minimize misuse. For example, such exemptions should require the relevant regulatory or management agency to show to some standard of proof that climate change processes were the proximate cause of alterations in baseline ecological conditions — air, land, or water temperature; hydrology or precipitation patterns; sea level; air quality — that made compliance with the regulatory mandate through the normal regulatory mechanisms impossible. Principled flexibility is just that: flexibility to deal with the climate change impacts that are beyond human control in a principled way to achieve general adaptation goals, not abdication of all environmental regulation and management.

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[291] 40 C.F.R. § 131.12 (2009).
[292] *Id.* § 131.12(a)(1).
[293] 33 U.S.C. § 1313(d)(1).
[294] *Id.* § 1313(d)(4).
[295] *See, e.g.*, Glicksman, *supra* note 140, at 862 (describing problems with federal lands agencies having too much discretion).

2. *Be Serious About Using Adaptive Management — and Change Both Natural Resources and Administrative Laws to Allow for It*

Especially with respect to natural resources and public lands management, climate change adaptation is the quintessential adaptive management problem, and both scientists and governments (at all levels) have acknowledged that adaptive management is a necessary approach to climate change adaptation.[296] Adjusting to climate change impacts and feedback loops will require regulatory and management agencies to respond to changing ecological conditions and shifting goals on a more or less continuous basis, preferably — per Principle #1 — in response to continuous informational inputs regarding exactly what is occurring. Legislatures and policymakers should thus incorporate comprehensive and pervasive adaptive management requirements and procedures into natural resource management statutes.[297]

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[296] For instance, Joshua J. Layler writes:

> What is new is a turning toward a more agile management perspective. To address climate change, managers will need to act over different spatial and temporal scales. The focus of restoration will need to shift from historic species assemblages to potential future ecosystem services. Active adaptive management based on potential future climate impact scenarios will need to be a part of everyday operations. And triage will likely become a critical option.

Joshua J. Lawler, *Climate Change Adaptation Strategies for Resource Management and Conservation Planning*, ANNALS N.Y. ACAD. SCI., Apr. 2009, at 79, 79. *See also* Glicksman, *supra* note 140, at 868–71; AUSTL. DEP'T OF ENV'T. & HERITAGE, CLIMATE CHANGE IMPACTS AND RISK MANAGEMENT: A GUIDE FOR BUSINESS AND GOVERNMENT 19–21 (2006), *available at* http://www.climatechange.gov.au/impacts/publications/pubs/risk-management.pdf (recommending adaptive management strategies in a risk management approach to adapting to climate change); Int'l Council for Local Envtl. Initiatives (ICLEI) Oceania Secretariat, Adaptive and Resilient Communities Program: Local Government Climate Change Adaptation Toolkit, http://www.iclei.org/index.php?id=adaptation-toolkit (last visited Dec. 27, 2009) (recommending the Australian Government's risk management/adaptive management approach); Tony Prato & Dan Fagre, *Coping with Climate Change*, ACTIONBIOSCIENCE, Oct. 2006, http://www.actionbioscience.org/environment/prato_fagre.html (on file with the Harvard Law School Library) ("Adaptive management (AM) is a science- and information-based approach that is well suited for managing natural resources for climate and landscape change."); Tompkins & Adger, *supra* note 66. One state agency described its approach this way:

> The uncertainty surrounding the extent and potential impacts of climate change requires a flexible management approach that can be continually revised and adapted. The Department's adaptive management strategies are iterative processes where monitoring and assessment continually refine our policies and management decisions. By closely linking research and management we are better able to anticipate and respond to the effects of climate change.

Commonwealth of Mass. Dep't of Fish & Game, Adapting to Climate Change, http://www.mass.gov/dfwele/climatechange.htm (last visited Dec. 27, 2009) (on file with the Harvard Law School Library).

[297] *See, e.g.*, Lara Whitely Binder, *Preparing for Climate Change in the U.S. Pacific Northwest*, 15 HASTINGS W.-N.W. J. ENVTL. L. & POL'Y 183, 189–90 (2009) (calling for adaptive planning in climate change adaptation policy); Ruhl, *Complex Adaptive System*, *supra* note 112, at 996 (advocating adaptive management as the proper process for regulating complex adaptive systems like ecosystems).

As several scholars have pointed out,[298] effective incorporation of adaptive management almost certainly requires adjustments to administrative law as well. Standard procedures for agency rulemaking are cumbersome and hence can discourage frequent amendment.[299] By demanding front-end justification for all measures proposed and taken, existing standards for judicial review can stifle an agency's willingness to experiment.[300]

With the exception of a few constitutional principles, however, administrative law requirements are statutory, subject to amendment. There has long been an assumption that the same basic administrative procedural requirements should apply to all agencies and in all regulatory contexts, regardless of the regulatory program or objective. In reality, most administrative law already imposes substantially different requirements in adjudications and in rulemakings, and Congress has already tweaked the basic requirements of the federal Administrative Procedure Act[301] in the ESA[302] and the CAA.[303] Climate change adaptation may productively become the occasion for the next generation of administrative law, the twenty-first century's answer to the mid-twentieth century's original administrative law revolution.

This is not an argument for wholesale repeal of public participation, judicial review, or any of the other safeguards that administrative law provides. Indeed, retaining current administrative procedures will be warranted and appropriate for many kinds of agency decisions, even in the climate change era. For example, current rulemaking requirements will remain useful in pollution regulation, especially with regard to technology-based limitations on emissions or effluent discharges, because getting the regulatory standard "right" is more important than the need to build capacity for flexible responses to changing conditions. These standards apply to facilities and reflect the technologies available to industries, not ecological conditions. Moreover, as Robert Glicksman has argued, effective enforcement against agencies remains critical for climate change adaptation measures.[304]

Nevertheless, this is a call for scholars and lawmakers to think creatively about how to restructure those legal safeguards and allow administrative agencies more breathing room to deal with climate change adaptation. For example, public lands managers may need some form of general plan-

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[298] Alfred R. Light, *Tales of the Tamiami Trail: Implementing Adaptive Management in Everglades Restoration*, 22 J. LAND USE & ENVTL. L. 59, 96–98 (2006); J.B. Ruhl, *Regulation by Adaptive Management — Is It Possible?*, 7 MINN. J. L. SCI. & TECH. 21, 30–31, 35–38, 53–57 (2005); John H. Davidson & Thomas Earl Geu, *The Missouri River and Adaptive Management: Protecting Ecological Function and Legal Process*, 80 NEB. L. REV. 816, 859–60 (2001). The discussion in this section has also benefited from my correspondence with Alex Camacho regarding one of his works in progress.

[299] Ruhl, *supra* note 298, at 36–37.

[300] *Id.* at 34–36. *See also* Farber, *supra* note 33, at 1399 (arguing that climate change requires increased incentives for agencies to act).

[301] 5 U.S.C. §§ 551-559, 701-706 (2006).

[302] 16 U.S.C. § 1533(a), (b) (2006).

[303] 42 U.S.C. § 7607 (2006).

[304] Glicksman, *supra* note 140, at 884–85.

ning requirements coupled with abbreviated administrative procedures for specific implementation decisions, periodic rather than continual judicial review for rationality, the ability to rely on postdecisional evaluations rather than predecisional justifications, or increased emergency authorities in order to achieve true capacity for adaptive management in the face of climate change impacts to resources and ecosystems.

3. *Prefer "No Regrets" Management Options First, Especially in the Face of Scientific Uncertainty*

One of the advantages climate change adaptation strategies often have is the ability to pursue two or more socially useful goals simultaneously.[305] These overlaps mean that governments can often choose, especially in the early stages of implementation, "no regrets" adaptation strategies — that is, measures that will increase resilience and the capacity to adapt to particular climate change impacts if those impacts actually occur, but will still enhance overall social welfare even if they do not materialize.[306]

As one example, I have argued that coastal areas can undertake many measures to adapt to climate change–driven sea level rise that will also enhance those communities' responses to hurricanes, storm surges, and storm- and sea-related public health problems.[307] Such dual- and triple-purpose measures minimize the political fallout that could occur from expenditures that the public might perceive as wasted or unnecessary while governments at all levels attempt to figure out what a locality's or region's actual climate change impacts are likely to be.

4. *Engage in Robust Decision Making with Respect to More Permanent or Expensive Adaptation Strategies to Help Retain Flexibility and Avoid Path Dependence*

Social scientists have noted that global climate change creates a key challenge for policymakers and scientists alike: "decision making under pervasive uncertainty associated with complex socio-ecological processes."[308]

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[305] For example, according to the IPCC, "[m]any actions that facilitate adaptation to climate change are undertaken to deal with current extreme events such as heatwaves and cyclones. Often, planned adaptation initiatives are also not undertaken as stand-alone measures, but embedded within broader sectoral initiatives such as water resource planning, coastal defence and disaster management planning." IPCC, ADAPTATION REPORT, *supra* note 7, at 719.

[306] *See* Heltberg et al., *supra* note 27, at 89 (defining "'no regrets' adaptation interventions" as "actions that generate net social benefits under all future scenarios of climate change and impacts"). As these authors further explain, "[n]o-regrets interventions are useful for hedging climate exposure because of the uncertainty over climate scenarios. They seek to build a general resilience that does not depend overly on detailed climate projections. However, 'no-regrets' does not mean cost-free: no-regrets options have real or opportunity costs or represent trade-offs." *Id.* at 95 (citations omitted).

[307] *See* Craig, *supra* note 186.

[308] John M. Anderies et al., *Panaceas, Uncertainty, and the Robust Control Framework in Sustainability Science*, 104 PROC. NAT'L ACAD. SCI. 15,194, 15,194 (2007).

One tendency in the face of such uncertainty and mounting pressure to "do *something*" is for decision makers to quickly and unadvisedly adopt simple "solutions" or panaceas that cannot reflect the true complexities of the problem,[309] then consider the problem "resolved." Failure to acknowledge the complexity and changing understanding of climate change impacts, however, will not lead to effective climate change adaptation strategies at any level.

Instead, decision makers should be cognizant that retaining as much flexibility as possible is itself an important adaptation strategy. This strategy is especially important during the early stages of climate change, while information regarding impacts and effects in particular locations and adequate models to generate future predictions are still being developed. Climate change adaptation law should thus encourage or require robust decision-making processes that identify adaptation measures that will be helpful under a variety of climate change scenarios for many adaptation decisions. These processes would be especially important for any decisions that involve significant investments in relatively permanent adaptation measures.

Adaptation to sea level rise is likely to be one of the first testing grounds for this subprinciple, especially in communities where residents call for expensive investments in dikes and sea walls to hold back the sea. However, reliance on robust decision making will also be relevant in decisions to site and construct sewage treatment plants, drinking water treatment plants, and hazardous waste treatment, storage, and disposal facilities; decisions whether to invest in new electric power generation, and what kind; decisions whether to invest in desalination plants, and where; decisions to allow new residential and industrial developments; decisions whether to construct new or replace old roads and highways; and decisions whether to construct new or replace old water infrastructure — in sum, in any decision regarding whether, where, and how to invest substantial capital in long-lasting infrastructure. This subprinciple thus also underscores the importance of Principle #3 and the general need for more coordinated decision making and planning.

Climate change adaptation decision making may thus require new tools that allow for flexibility in designing strategies. As one approach to flexibility, the IPCC has acknowledged "the value of a portfolio or mix of strategies that includes mitigation, adaptation, technological development (to enhance both adaptation and mitigation) and research (on climate science, impacts, adaptation and mitigation). Such portfolios could combine policies with incentive-based approaches . . . ."[310] More specifically on point for robust decision making, John M. Anderies and colleagues have described a "robust control" methodology for natural resource management, which "expos[es] how [management] policies distribute robustness and vulnerability across a given system" and "highlight[s] the importance of continual learning," as

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[309] *Id.*

[310] IPCC, ADAPTATION REPORT: SUMMARY FOR POLICYMAKERS, *supra* note 57, at 20.

well as the inevitability of trade-offs.[311] For the legal and policy realms, Daniel Farber has noted the potential of Robust Decision Making ("RDM")[312] as a tool for identifying particularly robust adaptation strategies — that is, "policies that perform well over many possible situations."[313] RDM is a computer-aided, statistical analysis of multiple future scenarios that helps planners both "to determine which characteristics of the scenarios are critical to the success or failure of particular strategies" and to generate increasingly robust adaptation policies.[314] Farber notes that RDM may be particularly useful for the types of large-scale, long-term infrastructure decisions discussed here.[315]

Principle #5: Accept — Really *Accept — That Climate Change Adaptation Will Often Be Painful*

Perhaps the most difficult aspect of climate change adaptation law, policy, and planning will be the acceptance of loss. Principled flexibility will require means of acknowledging ecological loss — the inability to save certain species in a "natural" environment or to preserve all existing ecosystem functions and services in particular locations. As the scientific journal *Nature* reported in 2004:

> Many plant and animal species are unlikely to survive climate change. New analyses suggest that 15–37% of a sample of 1,103 land plants and animals would eventually become extinct as a result of climate changes expected by 2050. For some of these species there will no longer be anywhere suitable to live. Others will be unable to reach places where the climate is suitable.[316]

Similarly, even with a massive effort to reduce non–climate change stressors to coral reefs, "the available evidence indicates that, at a global scale, reefs will undergo major changes in response to climate change," and even though they may not "disappear entirely," "[t]here is, nonetheless, great uncertainty whether the present economic and social capacity of coral reefs can be maintained."[317] Moreover, as the coral reef example illustrates, loss

[311] Anderies et al., *supra* note 308, at 15,198, 15,199.
[312] Farber, *supra* note 33, at 1395.
[313] *Id.* at 1396.
[314] *Id.*
[315] *Id.*
[316] *Feeling the Heat: Climate Change and Biodiversity Loss*, NATURE HIGHLIGHTS, Jan. 8, 2004, http://www.nature.com/nature/links/040108/040108-1.html (on file with the Harvard Law School Library). Indeed, an international panel of marine scientists concluded that ocean acidification alone "may render most regions chemically inhospitable to coral reefs by 2050." Cornelia Dean, *Rising Acidity Is Threatening Food Web of Oceans, Science Panel Says*, N.Y. TIMES, Jan. 31, 2009, at A12.
[317] Hughes et al., *supra* note 153, at 932.

of biodiversity can reduce "an ecosystem's ability to deliver goods and services for human well-being."[318]

With regard to individual species, protections in the wild can be supplemented by programs to preserve species in captivity, in hope of reintroducing them somewhere at some future date. With regard to ecosystems and their services, however, as with adaptation measures in general, "[d]ifficult choices will have to be made."[319] I have suggested elsewhere that a triage model of decision making — figuring out what is likely to survive with little or no human intervention, what is likely to be lost regardless of human effort, and what species and ecosystems would benefit most from human intervention — may prove helpful in responding to climate change impacts on water resources.[320] Other models, such as RDM, may prove more helpful in other climate change adaptation contexts, such as deciding among multiple proposed development plans or among different overall adaptation strategies.

The larger point for environmental and natural resources law, however, is that climate change adaptation presents lawmakers and policymakers with a difficult balancing act. Climate change adaptation law must incorporate an acceptance that some losses are inevitable while avoiding a morose complacency about losses that may be preventable. The law should not make the sacrifice of species, ecosystem function, and ecosystem services too easy. On the other hand, in the climate change era, comprehensive preservation is impossible. For this reason, climate change adaptation law must empower regulators and managers to cope with climate change–driven loss without automatically violating some legal requirement or otherwise incurring legal liability. Attempting to place blame for unavoidable losses simply wastes resources, reducing society's collective adaptive capacity to pursue more productive management and regulatory measures.

Conclusion

The climate change era is upon us, and phenomena such as the changing Arctic tundra, expanding pine beetle infestations, and Montana's warming trout streams are harbingers of the growing need for effective adaptation strategies. As in any situation that mixes scientific uncertainty, politics, and potentially large shifts in economic, social, and socio-ecological well-being, conflicts regarding how to proceed are inevitable.

Such conflicts, however, will only delay necessary decisions. The local character of many climate change impacts may assuage certain kinds of po-

[318] Swedish Biodiversity Ctr., Fact Sheet No. 2: Climate Change and Ecosystem Services 1, *available at* http://www.swedbio.com/dokument/fact%20sheet%20climate-en.pdf (last visited Dec. 27, 2009) (on file with the Harvard Law School Library).

[319] Binder, *supra* note 297, at 195.

[320] Craig, *supra* note 115, at 920–21.

litical conflicts — but they may also exacerbate conflicts among the various levels of government and subject-matter-based regulatory authorities.

This Article suggests, first and foremost, that two necessary steps in successful climate change adaptation will be (1) to adopt shared and overarching principles for climate change adaptation that can apply in a variety of scenarios, and (2) to change the law to remove existing barriers to, and to actively promote the implementation of, those principles in adaptation strategies. To those ends, this Article has argued for a principled flexibility model of climate change adaptation law to pursue goals of increasing the resilience and adaptive capacity of species, ecosystems, and socio-ecological systems. It has laid out five principles and several subprinciples for the climate change adaptation law of environmental regulation and natural resource management. Structurally, however, this Article also strongly suggests that climate change adaptation law must be bimodal: it must promote informed and principled flexibility when dealing with climate change impacts, especially impacts that affect baseline ecological conditions, while simultaneously embracing an unyielding commitment to stringent precautionary regulation when dealing with almost everything else. The five principles articulated in this Article give shape and content to that bimodality and can be applied in environmental regulation and natural resource management at all levels of government.

For example, consider again Montana's trout streams. Under current law, climate change impacts are likely to lead to forced and expensive establishment of TMDLs under the CWA in a futile attempt to achieve temperature standards that can no longer be achieved; listing of the trout species under the ESA, with consequent heroic (and again expensive) efforts to preserve viable populations in streams where survival is becoming impossible; curtailment of farmers' irrigation rights as a result of legal battles to preserve the trout; and takings litigation over those water rights. In many respects, California is already traveling this path, as the Delta smelt controversy highlights. Climate change adaptation dictates hard choices, but climate change adaptation law should not require this kind of futile and expensive attempt to preserve ecosystems in formations that can no longer exist.

Application of principled flexibility, in contrast, would prompt managers to acknowledge that Montana's trout streams are in fact changing and to adapt their use and management to evolving ecological realities. Under the first principle, relevant agencies at all levels of government should be gathering and sharing information regarding the flows and temperature of streams containing trout and other vulnerable species. Such investigations should be seeking answers to the following questions: How fast are temperatures rising? Where and how are water flow regimes changing? When, where, and to what extent are trout threatened? Do other stressors, such as thermal discharges regulated under the CWA or sediment runoff, increase the risks to trout in certain streams? Could land use changes to reduce sediment runoff or to increase the number of trees shading the stream bed reduce those vulnerabilities? If so, to what extent and for how long? What other impacts would such land use changes have? Where and when are withdrawals of water for agriculture already exacerbating threats to the trout? Where are conflicts likely to emerge in the near future? Where are trout likely to be extirpated, regardless of human effort?

As decision makers gather this information, they should begin to consider short- and long-term actions. If sediment runoff is exacerbating stream temperature increases, for example, Montana might consider enacting more stringent controls on nonpoint source pollution. A statewide project to plant trees along streambeds to shade the water might well be identified early as a "no regrets" adaptation measure for trout that might also produce ancillary benefits, such as stabilization of stream banks and creation of biodiversity-increasing riparian habitat. Similarly, given projected decreases in water supply, the various levels of government might choose to encourage farmers to install more efficient irrigation systems to reduce water demand. Nevertheless, the state should simultaneously consider the legal implications and perverse incentives such encouragement could have with respect to farmers' water rights, perhaps offering to pay for infrastructure improvements in exchange for farmers agreeing to return most of the newly "excess" water to the public domain. In addition, for budgetary reasons, such exchange programs might be adaptively phased in both temporally and geographically to match the progression of temperature impacts. On the trout side of the adaptation plan, fisheries managers should be adaptively managing the recreational trout fisheries, shifting fishing activity away from trout populations approaching extirpation thresholds. Throughout these first phases, coordination among the water quality, water allocation, fish and game, agriculture, tourism, recreation, and business sectors should be tight and transparent, with trade-offs among the various interests made publicly and explicitly.

Over the long term, of course, Montana might still lose a significant percentage — maybe all — of its coldwater trout, as well as all the livelihoods that trout used to support. Principled flexibility counsels the interested parties to try to make the best of this possible eventuality. For example, decision makers and the affected public at all levels of government should begin to think about whether the loss of trout should become the occasion to give in to the probably increasing pressures to allow Montana's streams to be drained for human water supply. Principled flexibility counsels "no," at least not without serious reflection on the implications of that wholesale elimination of riparian habitat for further adaptation and human well-being. Even if all trout are extirpated, streams with water left *in situ* are highly unlikely to remain uncolonized by other species, especially if managers are not actively trying to fight these changes but instead have plans and programs in place to opportunistically adapt to them. Continued monitoring will probably reveal continuing evolutions in the assemblage of species, some of which may end up being as economically valuable to residents as the trout had been. At the very least, the new assemblages are likely to provide humans with some ecosystem services that dry streambeds cannot, if only in terms of recreation and tourism. Ex ante commitments to water withdrawal, in other words, can maladaptively foreclose opportunities for human benefits while simultaneously increasing the adaptation stress on other species.

Principled flexibility thus encourages a climate change adaptation process that is immediate, pervasive, and, in some respects, draconian — but also staged, progressive, and adaptive. As researchers at the World Bank have noted, "The time lag until the full impacts of climate change unfold allows for sequencing responses . . . . While some adaptation responses must begin now, others can wait, allowing some room for experimentation and learning."[321] Caution is particularly warranted in making long-term infrastructure commitments, redesigning cities, planning relocations, and similar efforts — that is, in any decision that requires substantial economic investment and potentially creates path dependence. Moreover, robust strategies should be greatly preferred to non-robust ones.[322]

The new climate change adaptation law must similarly recognize and give legal effect to the critical differences between "no regrets" measures that should be undertaken immediately, such as information gathering and reductions in pollution, and longer-term adaptation plans and strategies, which should be based on greater understanding of the actual climate change impacts to particular socio-ecological systems than we currently possess. There are no panaceas for climate change adaptation, and there will be no final solution for some time to come.

[321] Heltberg et al., *supra* note 27, at 94.

[322] *See id.* at 95 (arguing that "investments in infrastructure and physical structures with a long expected life should be climate proofed").

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

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Systems for management of water throughout the developed world have been designed and operated under the assumption of stationarity. Stationarity—the idea that natural systems fluctuate within an unchanging envelope of variability—is a foundational concept that permeates training and practice in water-resource engineering. It implies that any variable (e.g., annual streamflow or annual flood peak) has a time-invariant (or 1-year–periodic) probability density function (pdf), whose properties can be estimated from the instrument record. Under stationarity, pdf estimation errors are acknowledged, but have been assumed to be reducible by additional observations, more efficient estimators, or regional or paleohydrologic data. The pdfs, in turn, are used to evaluate and manage risks to water supplies, waterworks, and floodplains; annual global investment in water infrastructure exceeds U.S.$500 billion (*1*).

The stationarity assumption has long been compromised by human disturbances in river basins. Flood risk, water supply, and water quality are affected by water infrastructure, channel modifications, drainage works, and land-cover and land-use change. Two other (sometimes indistinguishable) challenges to stationarity have been externally forced, natural climate changes and low-frequency, internal variability (e.g., the Atlantic multidecadal oscillation) enhanced by the slow dynamics of the oceans and ice sheets (*2*, *3*). Planners have tools to adjust their analyses for known human disturbances within river basins, and justifiably or not, they generally have considered natural change and variability to be sufficiently small to allow stationarity-based design.

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An uncertain future challenges water planners.

In view of the magnitude and ubiquity of the hydroclimatic change apparently now under way, however, we assert that stationarity is dead and should no longer serve as a central, default assumption in water-resource risk assessment and planning. Finding a suitable successor is crucial for human adaptation to changing climate.

How did stationarity die? Stationarity is dead because substantial anthropogenic change of Earth's climate is altering the means and extremes of precipitation, evapotranspiration, and rates of discharge of rivers (*4*, *5*) (see figure, above). Warming augments atmospheric humidity and water transport. This increases precipitation, and possibly flood risk, where prevailing atmospheric water-vapor fluxes converge (*6*). Rising sea level induces gradually heightened risk of contamination of coastal freshwater supplies. Glacial meltwater temporarily enhances water availability, but glacier and snow-pack losses diminish natural seasonal and interannual storage (*7*).

Anthropogenic climate warming appears to be driving a poleward expansion of the subtropical dry zone (*8*), thereby reducing runoff in some regions. Together, circulatory and thermodynamic responses largely explain the picture of regional gainers and losers of sustainable freshwater availability that has emerged from climate models (see figure, p. 574).

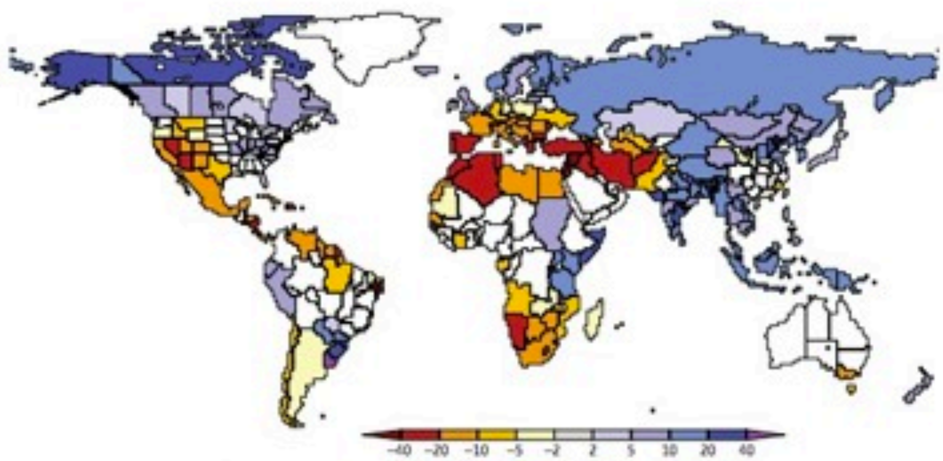
Why now? That anthropogenic climate change affects the water cycle (*9*) and water supply (*10*) is not a new finding. Nevertheless, sensible objections to discarding stationarity have been raised. For a time, hydroclimate had not demonstrably exited the envelope of natural variability and/or the effective range of optimally operated infrastructure (*11*, *12*). Accounting for the substantial uncertainties of climatic parameters estimated from short records (*13*) effectively hedged against small climate changes. Additionally, climate projections were not considered credible (*12*, *14*).

Recent developments have led us to the opinion that the time has come to move beyond the wait-and-see approach. Projections of runoff changes are bolstered by the recently demonstrated retrodictive skill of climate models. The global pattern of observed annual streamflow trends is unlikely to have arisen from unforced variability and is consistent with modeled response to climate forcing (*15*). Paleohydrologic studies suggest that small changes in mean climate might produce large changes in extremes (*16*), although attempts to detect a recent change in global flood frequency have been equivocal (*17*, *18*). Projected changes in runoff during the multidecade lifetime of major water infrastructure projects begun now are large enough to push hydroclimate beyond the range of historical behaviors (*19*). Some regions have little infrastructure to buffer the impacts of change.

Stationarity cannot be revived. Even with aggressive mitigation, continued warming is very likely, given the residence time of atmospheric CO_2 and the thermal inertia of the Earth system (*4*, *20*).

A successor. We need to find ways to identify nonstationary probabilistic models of relevant environmental variables and to use those models to optimize water systems. The challenge is daunting. Patterns of change are complex; uncertainties are large; and the knowledge base changes rapidly.

Under the rational planning framework advanced by the Harvard Water Program (*21*, *22*), the assumption of stationarity was



Human influences. Dramatic changes in runoff volume from ice-free land are projected in many parts of the world by the middle of the 21st century (relative to historical conditions from the 1900 to 1970 period). Color denotes percentage change (median value from 12 climate models). Where a country or smaller political unit is colored, 8 or more of 12 models agreed on the direction (increase versus decrease) of runoff change under the Intergovernmental Panel on Climate Change's "SRES A1B" emissions scenario.

combined with operations research, statistics, and welfare economics to formulate design problems as trade-offs of costs, risks, and benefits dependent on variables such as reservoir volume. These trade-offs were evaluated by optimizations or simulations using either long historical streamflow time series or stochastic simulations of streamflow based on properties of the historical time series.

This framework can be adapted to changing climate. Nonstationary hydrologic variables can be modeled stochastically to describe the temporal evolution of their pdfs, with estimates of uncertainty. Methods for estimating model parameters can be developed to combine historical and paleohydrologic measurements with projections of multiple climate models, driven by multiple climate-forcing scenarios.

Rapid flow of such climate-change information from the scientific realm to water managers will be critical for planning, because the information base is likely to change rapidly as climate science advances during the coming decades. Optimal use of available climate information will require extensive training of (both current and future) hydrologists, engineers, and managers in nonstationarity and uncertainty. Reinvigorated development of methodology may require focused, interdisciplinary efforts in the spirit of the Harvard Water Program.

A stable institutional platform for climate predictions and climate-information delivery may help (*23*). Higher-resolution simulations of the physics of the global land-atmosphere system that focus on the next 25 to 50 years are crucial. Water managers who are developing plans for their local communities to adapt to climate change will not be best served by a model whose horizontal grid has divisions measured in hundreds of kilometers. To facilitate information transfer in both directions between climate science and water management, the climate models need to include more explicit and faithful representation of surface- and ground-water processes, water infrastructure, and water users, including the agricultural and energy sectors. Treatments of land-cover change and land-use management should be routinely included in climate models. Virtual construction of dams, irrigation of crops, and harvesting of forests within the framework of climate models can be explored in a collaboration between climate scientists and resource scientists and managers.

Modeling should be used to synthesize observations; it can never replace them. Assuming climatic stationarity, hydrologists have periodically relocated stream gages (*24*) so that they could acquire more perspectives on what was thought to be a fairly constant picture. In a nonstationary world, continuity of observations is critical.

The world today faces the enormous, dual challenges of renewing its decaying water infrastructure (*25*) and building new water infrastructure (*26*). Now is an opportune moment to update the analytic strategies used for planning such grand investments under an uncertain and changing climate.

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CLIMATOLOGY

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Unprecedented 21st century drought risk in the American Southwest and Central Plains

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In the Southwest and Central Plains of Western North America, climate change is expected to increase drought severity in the coming decades. These regions nevertheless experienced extended Medieval-era droughts that were more persistent than any historical event, providing crucial targets in the paleoclimate record for benchmarking the severity of future drought risks. We use an empirical drought reconstruction and three soil moisture metrics from 17 state-of-the-art general circulation models to show that these models project significantly drier conditions in the later half of the 21st century compared to the 20th century and earlier paleoclimatic intervals. This desiccation is consistent across most of the models and moisture balance variables, indicating a coherent and robust drying response to warming despite the diversity of models and metrics analyzed. Notably, future drought risk will likely exceed even the driest centuries of the Medieval Climate Anomaly (1100–1300 CE) in both moderate (RCP 4.5) and high (RCP 8.5) future emissions scenarios, leading to unprecedented drought conditions during the last millennium.

INTRODUCTION

Millennial-length hydroclimate reconstructions over Western North America (*1*–*4*) feature notable periods of extensive and persistent Medieval-era droughts. Such "megadrought" events exceeded the duration of any drought observed during the historical record and had profound impacts on regional societies and ecosystems (*2*, *5*, *6*). These past droughts illustrate the relatively narrow view of hydroclimate variability captured by the observational record, even as recent extreme events (*7*–*9*) highlighted concerns that global warming may be contributing to contemporary droughts (*10*, *11*) and will amplify drought severity in the future (*11*–*15*). A comprehensive understanding of global warming and 21st century drought therefore requires placing projected hydroclimate trends within the context of drought variability over much longer time scales (*16*, *17*). This would also allow us to establish the potential risk (that is, likelihood of occurrence) of future conditions matching or exceeding the severest droughts of the last millennium.

Quantitatively comparing 21st century drought projections from general circulation models (GCMs) to the paleo-record is nevertheless a significant technical challenge. Most GCMs provide soil moisture diagnostics, but their land surface models often vary widely in terms of parameterizations and complexity (for example, soil layering and vegetation). There are few large-scale soil moisture measurements that can be easily compared to modeled soil moisture, and none for intervals longer than the satellite record. Instead, drought is typically monitored in the real world using offline models or indices that can be estimated from more widely measured data, such as temperature and precipitation.

One common metric is the Palmer Drought Severity Index (PDSI) (*18*), widely used for drought monitoring and as a target variable for proxy-based reconstructions (*1*, *2*). PDSI is a locally normalized index of soil moisture availability, calculated from the balance of moisture supply (precipitation) and demand (evapotranspiration). Because PDSI is normalized on the basis of local average moisture conditions, it can be used to compare variability and trends in drought across regions. Average moisture conditions (relative to a defined baseline) are denoted by PDSI = 0; negative PDSI values indicate drier than average conditions (droughts), and positive PDSI values indicate wetter than normal conditions (pluvials). PDSI is easily calculated from GCMs using variables from the atmosphere portion of the model (for example, precipitation, temperature, and humidity) and can be compared directly to observations. However, whereas recent work has demonstrated that PDSI is able to accurately reflect the surface moisture balance in GCMs (*19*), other studies have highlighted concerns that PDSI may overestimate 21st century drying because of its relatively simple soil moisture accounting and lack of direct CO2 effects that are expected to reduce evaporative losses (*12*, *20*, *21*). We circumvent these concerns by using a more physically based version of PDSI (*13*) (based on the Penman-Monteith potential evapotranspiration formulation) in conjunction with soil moisture from the GCMs to demonstrate robust drought responses to climate change in the Central Plains (105°W–92°W, 32°N–46°N) and the Southwest (125°W–105°W, 32°N–41°N) regions of Western North America.

RESULTS

We calculate summer season [June-July-August (JJA)] PDSI and integrated soil moisture from the surface to ~30-cm (SM-30cm) and ~2- to 3-m (SM-2m) depths from 17 GCMs (tables S1 and S2) in phase 5 of the Coupled Model Intercomparison Project (CMIP5) database (*22*). We focus our analyses and presentation on the RCP 8.5 "business-as-usual" high emissions scenario, designed to yield an approximate top-of-atmosphere radiative imbalance of +8.5 W m^{-2} by 2100. We also conduct the same analyses for a more moderate emissions scenario (RCP 4.5).

Over the calibration interval (1931–1990), the PDSI distributions from the models are statistically indistinguishable from the North American Drought Atlas (NADA) (two-sided Kolmogorov-Smirnov test, $p \geq 0.05$), although there are some significant deviations in some models during other historical intervals. North American drought variability during the historical period in both models and observations is driven primarily by ocean-atmosphere teleconnections,

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internal variability in the climate system that is likely to not be either consistent across models or congruent in time between the observations and models, and so such disagreements are unsurprising. In the multimodel mean, all three moisture balance metrics show markedly consistent drying during the later half of the 21st century (2050–2099) (Fig. 1; see figs. S1 to S4 for individual models). Drying in the Southwest is more severe (RCP 8.5: PDSI = −2.31, SM-30cm = −2.08, SM-2m = −2.98) than that over the Central Plains (RCP 8.5: PDSI = −1.89, SM-30cm = −1.20, SM-2m = −1.17). In both regions, the consistent cross-model drying trends are driven primarily by the forced response to increased greenhouse gas concentrations (*13*), rather than by any fundamental shift in ocean-atmosphere dynamics [indeed, there is a wide disparity across models regarding the strength and fidelity of the simulated teleconnections over North America (*23*)]. In the Southwest, this forcing manifests as both a reduction in cold season precipitation (*24*) and an increase in potential evapotranspiration (that is, evaporative demand increases in a warmer atmosphere) (*13*, *25*) acting in concert to reduce soil moisture. Even though cold season precipitation is actually expected to increase over parts of California in our Southwest region (*24*, *26*), the increase in evaporative demand is still sufficient to drive a net reduction in soil moisture. Over the Central Plains, precipitation responses during the spring and summer seasons (the main

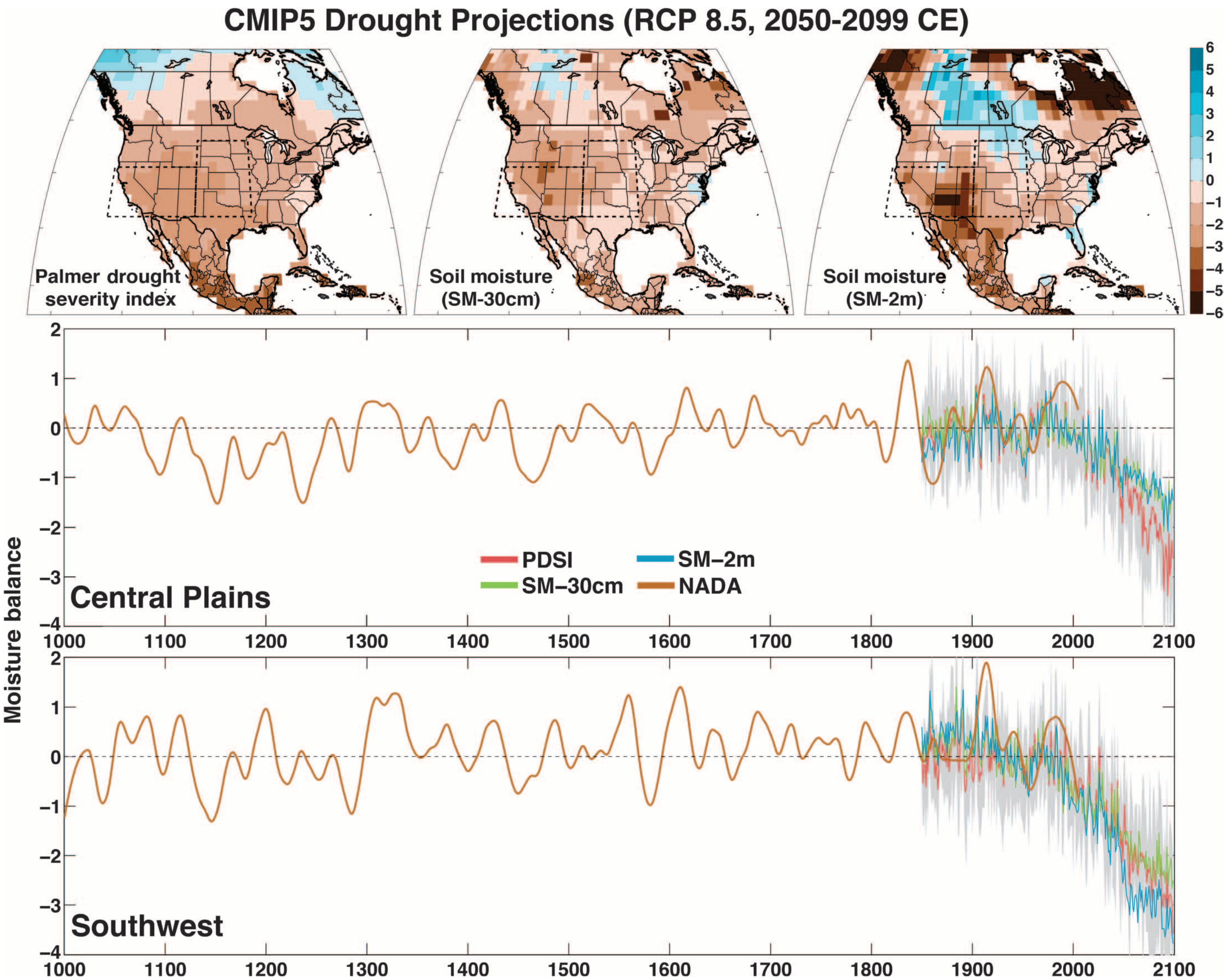

Fig. 1. Top: Multimodel mean summer (JJA) PDSI and standardized soil moisture (SM-30cm and SM-2m) over North America for 2050–2099 from 17 CMIP5 model projections using the RCP 8.5 emissions scenario. SM-30cm and SM-2m are standardized to the same mean and variance as the model PDSI over the calibration interval from the associated historical scenario (1931–1990). Dashed boxes represent the regions of interest: the Central Plains (105°W–92°W, 32°N–46°N) and the Southwest (125°W–105°W, 32°N–41°N). Bottom: Regional average time series of the summer season moisture balance metrics from the NADA and CMIP5 models. The observational NADA PDSI series (brown) is smoothed using a 50-year loess spline to emphasize the low-frequency variability in the paleo-record. Model time series (PDSI, SM-30cm, and SM-2m) are the multimodel means averaged across the 17 CMIP5 models, and the gray shaded area is the multimodel interquartile range for model PDSI.

seasons of moisture supply) are less consistent across models, and the drying is driven primarily by the increased evaporative demand. Indeed, this increase in potential evapotranspiration is one of the dominant drivers of global drought trends in the late 21st century, and previous work with the CMIP5 archive demonstrated that the increased evaporative demand is likely to be sufficient to overcome precipitation increases in many regions (*13*). In the more moderate emissions scenario (RCP 4.5), both the Southwest (RCP 4.5: PDSI = −1.49, SM-30cm = −1.63, SM-2m = −2.39) and Central Plains (RCP 4.5: PDSI = −1.21, SM-30cm = −0.89, SM-2m = −1.17) still experience significant, although more modest, drying into the future, as expected (fig. S5).

In both regions, the model-derived PDSI closely tracks the two soil moisture metrics (figs. S6 and S7), correlating significantly for most models and model intervals (figs. S8 and S9). Over the historical simulation, average model correlations (Pearson's r) between PDSI and SM-30cm are +0.86 and +0.85 for the Central Plains and Southwest, respectively. Correlations weaken very slightly for PDSI and SM-2m: +0.84 (Central Plains) and +0.83 (Southwest). The correlations remain strong into the 21st century, even as PDSI and the soil moisture variables occasionally diverge in terms of long-term trends. There is no evidence, however, for systematic differences between the PDSI and modeled soil moisture across the model ensemble. For example, whereas the PDSI trends are drier than the soil moisture condition over the Southwest in the ACCESS1-0 model, PDSI is actually less dry than the soil moisture in the MIROC-ESM and NorESM1-M simulations over the same region (fig. S7). These outlier observations, showing no consistent bias, in conjunction with the fact that the overall comparison between PDSI and modeled soil moisture is markedly consistent, provide mutually consistent support for the characterization of surface moisture balance by these metrics in the model projections.

For estimates of observed drought variability over the last millennium (1000–2005), we use data from the NADA, a tree-ring based reconstruction of JJA PDSI. Comparisons between the NADA and model moisture are shown in the bottom panels of Fig. 1. In the NADA, both the Central Plains (Fig. 2) and Southwest (Fig. 3) are drier during the Medieval megadrought interval (1100–1300 CE) than either the Little

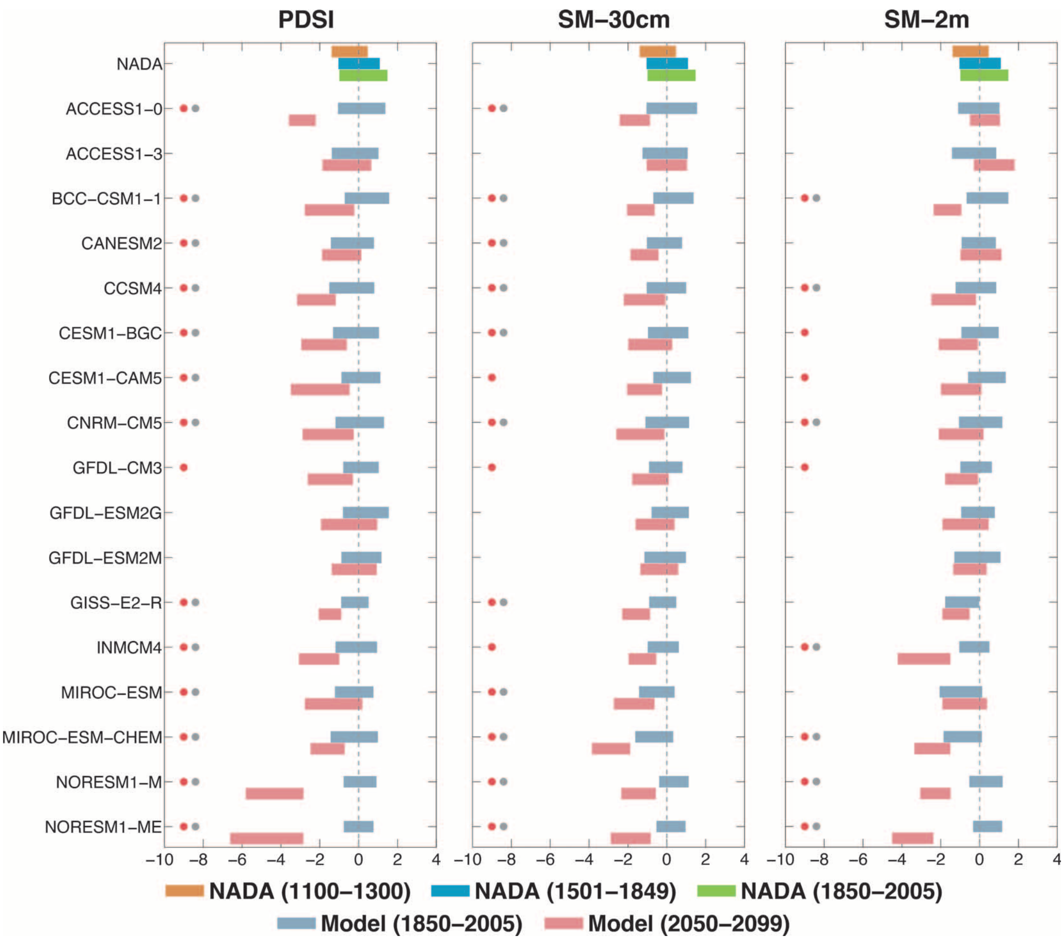

Fig. 2. Interquartile range of PDSI and soil moisture from the NADA and CMIP5 GCMs, calculated over various time intervals for the Central Plains. The groups of three stacked bars at the top of each column are from the NADA PDSI: 1100–1300 (the time of the Medieval-era megadroughts, brown), 1501–1849 (the Little Ice Age, blue), and 1850–2005 (the historical period, green). Purple and red bars are for the modeled historical period (1850–2005) and late 21st century (2050–2099) period, respectively. Red dots indicate model 21st century drought projections that are significantly drier than the model simulated historical periods. Gray dots indicate model 21st century drought projections that are significantly drier than the Medieval-era megadrought period in the NADA.

Ice Age (1501–1849) or historical periods (1850–2005). For nearly all models, the 21st century projections under the RCP 8.5 scenario reveal dramatic shifts toward drier conditions. Most models (indicated with a red dot) are significantly drier (one-sided Kolmogorov-Smirnov test, $p \leq 0.05$) in the latter part of the 21st century (2050–2099) than during their modeled historical intervals (1850–2005). Strikingly, shifts in projected drying are similarly significant in most models when measured against the driest and most extreme megadrought period of the NADA from 1100 to 1300 CE (gray dots). Results are similar for the more moderate RCP 4.5 emissions scenario (figs. S10 and S11), which still indicates widespread drying, albeit at a reduced magnitude for many models. Although there is some spread across the models and metrics, only two models project wetter conditions in RCP 8.5. In the Central Plains, SM-2m is wetter in ACCESS1-3, with little change in SM-30cm and slightly wetter conditions in PDSI. In the Southwest, CanESM2 projects markedly wetter SM-2m conditions; PDSI in the same model is slightly wetter, whereas SM-30cm is significantly drier.

When the RCP 8.5 multimodel ensemble is pooled together (Fig. 4), projected changes in the Central Plains and Southwest (2050–2099 CE) for all three moisture balance metrics are significantly drier compared to both the modern model interval (1850–2005 CE) and 1100–1300 CE in the NADA (one-sided Kolmogorov-Smirnov test, $p \leq 0.05$). In the case of SM-2m in the Southwest, the density function is somewhat flattened, with an elongated right (wet) tail. This distortion arises from the disproportionate contribution to the density function from the wetting in the five CanESM2 ensemble members. Even with this contribution, however, the SM-2m drying in the multimodel ensemble is still significant. Results are nearly identical for the pooled RCP 4.5 multimodel ensemble (fig. S12), which still indicates a significantly drier late 21st century compared to either the historical interval or Medieval megadrought period.

With this shift in the full hydroclimate distribution, the risk of decadal or multidecadal drought occurrences increases substantially. We calculated the risk (*17*) of decadal or multidecadal drought occurrences for two periods in our multimodel ensemble: 1950–2000 and 2050–2099 (Fig. 5). During the historical period, the risk of a multidecadal megadrought is quite small: <12% for both regions and all moisture metrics. Under RCP 8.5, however, there is ≥80% chance of a multidecadal drought during 2050–2099 for PDSI and SM-30cm in the Central Plains and for all three moisture metrics in the Southwest. Drought risk is reduced slightly in RCP 4.5 (fig. S13), with largest reductions in multidecadal drought risk over the Central Plains. Ultimately, the consistency of our results suggests an exceptionally high risk of a multidecadal megadrought occurring over the Central Plains and Southwest regions during the late 21st century, a level of aridity exceeding even the persistent megadroughts that characterized the Medieval era.

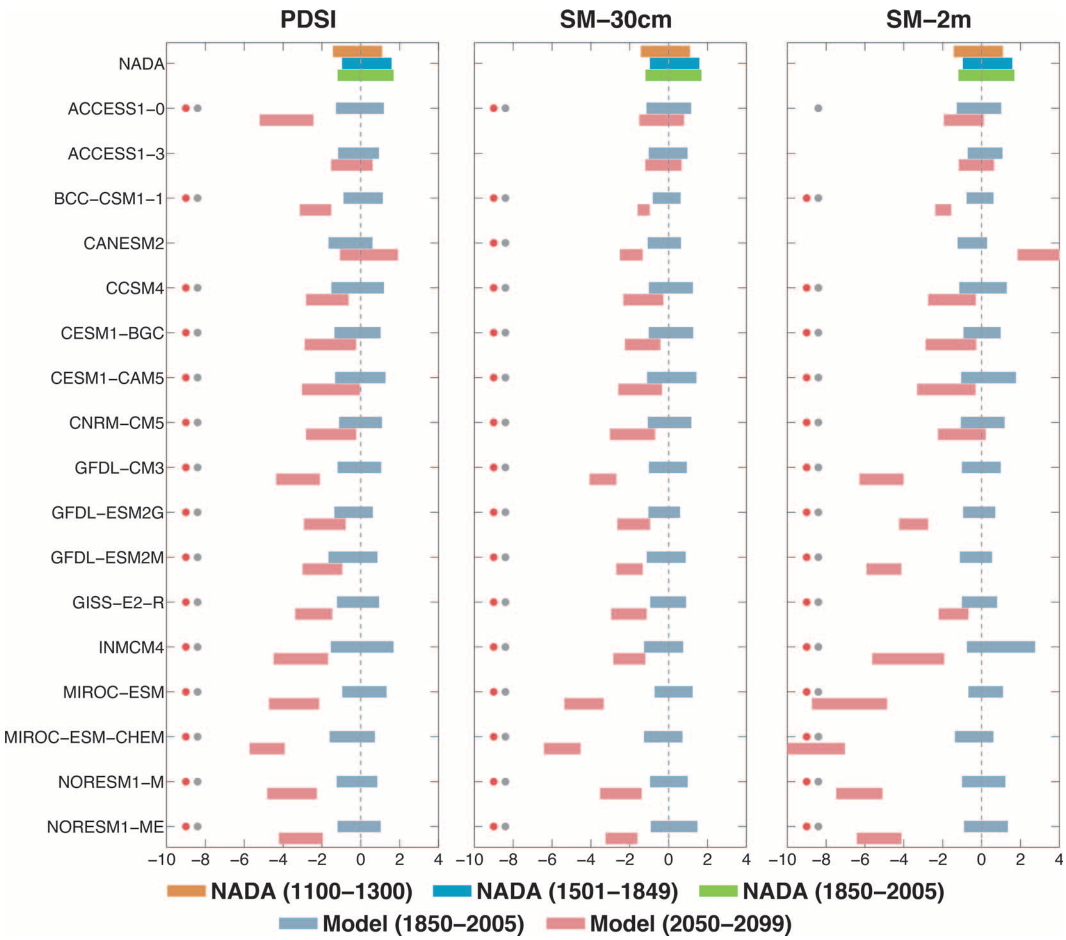

Fig. 3. Same as Fig. 2, but for the Southwest.

DISCUSSION

Within the body of literature investigating North American hydroclimate, analyses of drought variability in the historical and paleoclimate records are often separate from discussions of global warming–induced changes in future hydroclimate. This disconnection has traditionally made it difficult to place future drought projections within the context of observed and reconstructed natural hydroclimate variability. Here,

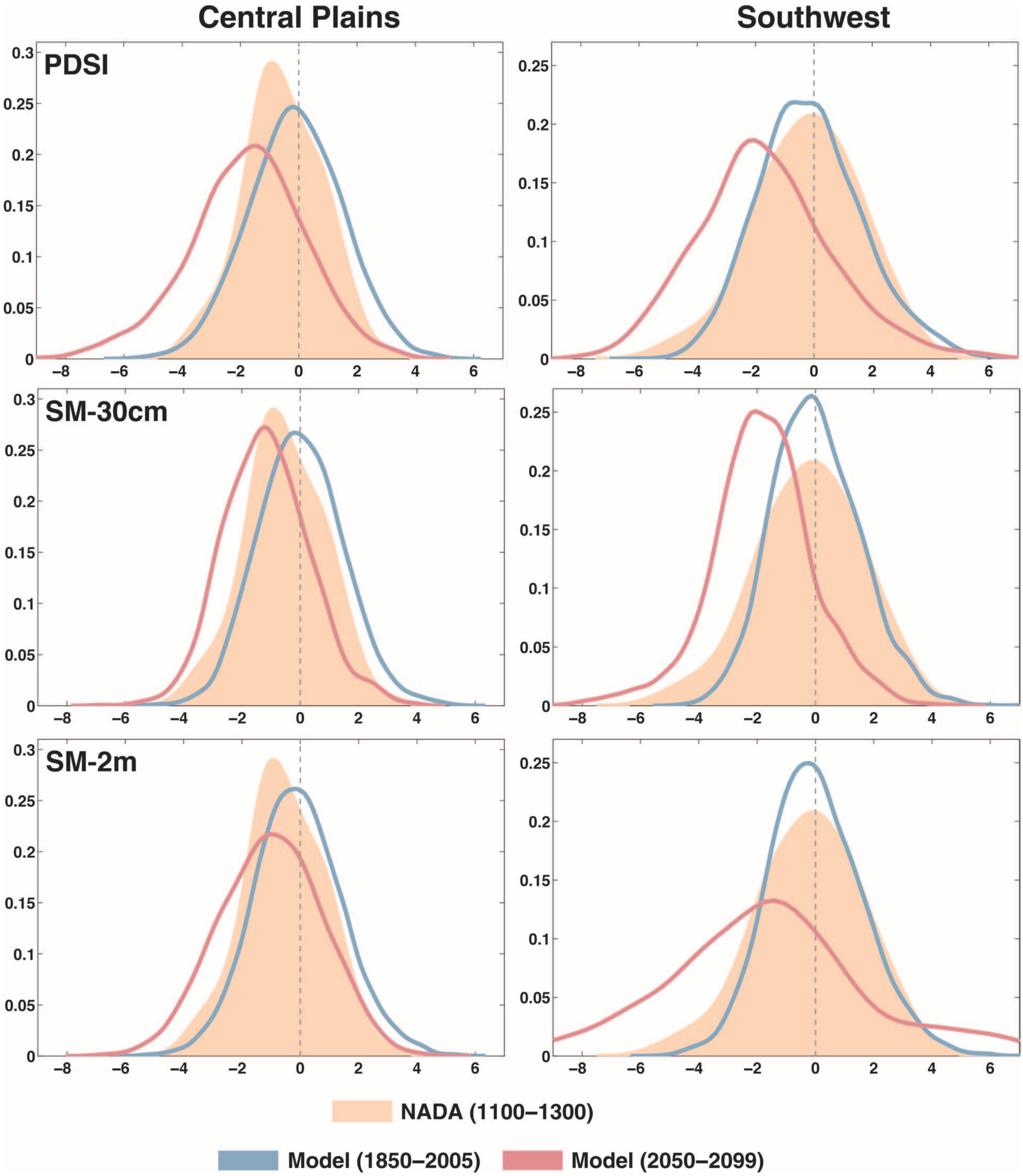

Fig. 4. Kernel density functions of PDSI, SM-30cm, and SM-2m for the Central Plains and Southwest, calculated from the NADA and the GCMs. The NADA distribution (brown shading) is from 1100–1300 CE, the timing of the medieval megadroughts. Blue lines represent model distributions calculated from all years from all models pooled over the historical scenario (1850–2005 CE). Red lines are for all model years pooled from the RCP 8.5 scenario (2050–2099 CE).

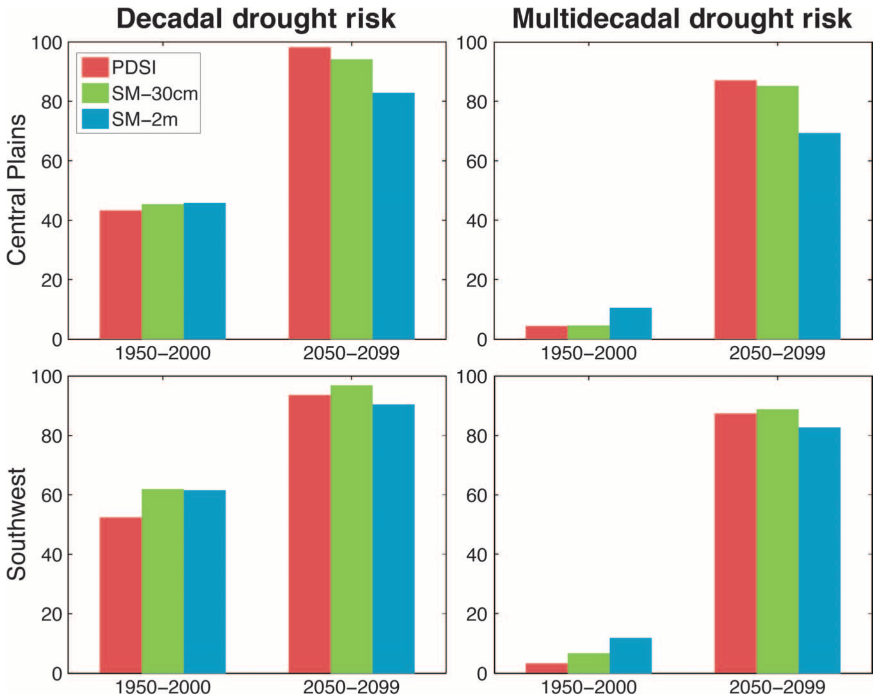

Fig. 5. Risk (percent chance of occurrence) of decadal (11-year) and multidecadal (35-year) drought, calculated from the multimodel ensemble for PDSI, SM-30cm, and SM-2m. Risk calculations are conducted for two separate model intervals: 1950–2000 (historical scenario) and 2050–2099 (RCP 8.5). Results for the Central Plains are in the top row, and those for the Southwest are in the bottom row.

we have demonstrated that the mean state of drought in the late 21st century over the Central Plains and Southwest will likely exceed even the most severe megadrought periods of the Medieval era in both high and moderate future emissions scenarios, representing an unprecedented fundamental climate shift with respect to the last millennium. Notably, the drying in our assessment is robust across models and moisture balance metrics. Our analysis thus contrasts sharply with the recent emphasis on uncertainty about drought projections for these regions (*21*, *27*), including the most recent Intergovernmental Panel on Climate Change assessment report (*28*).

Our results point to a remarkably drier future that falls far outside the contemporary experience of natural and human systems in Western North America, conditions that may present a substantial challenge to adaptation. Human populations in this region, and their associated water resources demands, have been increasing rapidly in recent decades, and these trends are expected to continue for years to come (*29*). Future droughts will occur in a significantly warmer world with higher temperatures than recent historical events, conditions that are likely to be a major added stress on both natural ecosystems (*30*) and agriculture (*31*). And, perhaps most importantly for adaptation, recent years have witnessed the widespread depletion of nonrenewable groundwater reservoirs (*32*, *33*), resources that have allowed people to mitigate the impacts of naturally occurring droughts. In some cases, these losses have even exceeded the capacity of Lake Mead and Lake Powell, the two major surface reservoirs in the region (*34*, *35*). Combined with the likelihood of a much drier future and increased demand, the loss of groundwater and higher temperatures will likely exacerbate the impacts of future droughts, presenting a major adaptation challenge for managing ecological and anthropogenic water needs in the region.

MATERIALS AND METHODS

Estimates of drought variability over the historical period and the last millennium used the latest version of the NADA (*1*), a tree ring–based reconstruction of summer season (JJA) PDSI. All statistics were based on regional PDSI averages over the Central Plains (105°W–92°W, 32°N–46°N) and the Southwest (125°W–105°W, 32°N–41°N). We restricted our analysis to 1000–2005 CE; before 1000 CE, the quality of the reconstruction in these regions declines.

The 21st century drought projections used output from GCM simulations in the CMIP5 database (*22*) (table S1). All models represent one or more continuous ensemble members from the historical (1850–2005 CE) and RCP 4.5 (15 models available) and 8.5 (17 models available) emissions scenarios (2006–2099 CE). We used the same methodology as in (*13*) to calculate model PDSI for the full interval (1850–2099 CE), using the Penman-Monteith formulation of potential evapotranspiration. The baseline period for calibrating and standardizing the model PDSI anomalies was 1931–1990 CE, the same baseline period as the NADA PDSI. Negative model PDSI values therefore indicate drier conditions than the average for 1931–1990.

To augment the model PDSI calculations and comparisons with observed drought variability in the NADA, we also calculated standardized soil moisture metrics from the GCMs for two depths: ~30 cm (SM-30cm) and ~2 to 3 m (SM-2m) (table S2). For these soil moisture metrics, the total soil moisture from the surface was integrated to these depths and averaged over JJA. At each grid cell, we then standardized SM-30cm and SM-2m to match the same mean and interannual SD for the model PDSI over 1931–1990. This allows for direct comparison of variability and trends between model PDSI and model soil moisture and between the model metrics (PDSI, SM-30cm, and SM-2m) and the NADA (PDSI) while still independently preserving any low-frequency variability or trends in the soil moisture that may be distinct from the PDSI calculation. The soil moisture standardization does not impose any artificial constraints that would force the three metrics to agree in terms of variability or future trends, allowing SM-30cm and SM-2m to be used as indicators of drought largely independent of PDSI.

Risk of decadal and multidecadal megadrought occurrence in the multimodel ensemble is estimated from 1000 Monte Carlo realizations of each moisture balance metric (PDSI, SM-30cm, and SM-2m), as in (*17*). This method entails estimating the mean and SD of a given drought index (for example, PDSI or soil moisture) over a reference period (1901–2000), then subtracting that mean and SD from the full record (1850–2100) to produce a modified z score. The differences between the reference mean and SD are then used to conduct (white noise) Monte Carlo simulations of the future (2050–2100) to emulate the statistics of that era. The fraction of Monte Carlo realizations exhibiting a decadal or multidecadal drought are then calculated from each Monte Carlo simulation of each experiment in both regions considered here. Finally, these risks from each model are averaged together to yield the overall risk estimates reported here. Additional details on the methodology can be found in (*17*).

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org
Fig. S1. For the individual models, ensemble mean soil moisture balance (PDSI, SM-30cm, and SM-2m) for 2050–2099: ACCESS1.0, ACCESS1.3, BCC-CSM1.1, and CanESM2.
Fig. S2. Same as fig. S1, but for CCSM4, CESM1-BGC, CESM-CAM5, and CNRM-CM5.
Fig. S3. Same as fig. S1, but for GFDL-CM3, GFDL-ESM2G, GFDL-ESM2M, and GISS-E2-R.
Fig. S4. Same as fig. S1, but for INMCM4.0,MIROC-ESM, MIROC-ESM-CHEM, NorESM1-M, and NorESM1-ME models.
Fig. S5. Same as Fig. 1, but for the RCP 4.5 scenario.
Fig. S6. Regional average moisture balance time series (historical + RCP 8.5) from the first ensemble member of each model over the Central Plains.
Fig. S7. Same as fig. S6, but for the Southwest.
Fig. S8. Pearson's correlation coefficients for three time intervals from the models over the Central Plains: PDSI versus SM-30cm, PDSI versus SM-2m, and SM-30cm versus SM-2m.
Fig. S9. Same as fig. S8, but for the Southwest.
Fig. S10. Same as Fig. 2, but for the RCP 4.5 scenario.
Fig. S11. Same as Fig. 3, but for the RCP 4.5 scenario.
Fig. S12. Same as Fig.4, but for the RCP 4.5 scenario.
Fig. S13. Same as Fig. 5, but for the RCP 4.5 scenario.
Table S1. Continuous model ensembles from the CMIP5 experiments (1850–2099, historical + RCP8.5 scenario) used in this analysis, including the modeling center or group that supplied the output, the number of ensemble members, and the approximate spatial resolution.
Table S2. The number of soil layers integrated for our CMIP5 soil moisture metrics (SM-30cm and SM-2m), and the approximate depth of the bottom soil layer.

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Benjamin I. Cook, Toby R. Ault and Jason E. Smerdon (February 12, 2015)
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THE IMPACT OF CLIMATE CHANGE
ON
NEW MEXICO'S WATER SUPPLY
AND
ABILITY TO MANAGE WATER RESOURCES

New Mexico Office of the State Engineer/Interstate Stream Commission
John. R. D'Antonio, P.E., State Engineer

July 2006

http://www.ose.state.nm.us/more_info_drought_status.html

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Anne Watkins, Special Assistant to the State Engineer, served as Principal Author of the report.

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EXECUTIVE SUMMARY

Governor Bill Richardson, recognizing that the biggest impact of climate change on New Mexico will be its affect on the State's water resources, in his Executive Order 2005-033 directed "The Office of the State Engineer to work with other state agencies, with local and federal agencies, and with the State's research institutions to prepare an analysis of the impact of climate change on the State's water supply and ability to manage its water resources. A report summarizing findings shall be completed no later than July 2006." This report will therefore address only water issues, although it is important to consider it along with the New Mexico Environment Department's December, 2005 report on the impacts of climate change throughout New Mexico.

Global warming and climate change are increasingly understood because a growing number of researchers internationally are contributing to the body of scientific knowledge and to modeling capacity. Although to date little modeling is available that is specific to New Mexico, results from global climate models (GCMs) were utilized for the projections reported in Section II. The impacts to the State are anticipated to be significant for water managers and users, with changes to both supply and demand including:

---temperatures have already risen in New Mexico and are predicted to continue to increase;

---changes in snowpack elevations and water equivalency;

---changes in available water volumes and in the timing of water availability;

---increasing precipitation in the form of rain rather than snow due to increasing temperatures;

---smaller spring runoff volumes and/or earlier runoff that will impact water availability for irrigation and for ecological and species needs;

---milder winters and hotter summers, resulting in longer growing seasons and increased plant and human water use;

---increased evaporative losses from reservoirs, streamflows and soils due to hotter, drier conditions;

---increased evapotranspiration by agricultural and riparian plants;

---an increase in extreme events, including both drought and floods.

Incorporating climate change into water planning has historically been challenging due to the continued level of prediction uncertainty, coupled with the myriad additional pressures faced by water resource planners. Climate change needs to be added as "another pressure" along with population growth, changing demographics, existing climate variability, increasing water demand and availability challenges, land use, species protection and other ecosystem demands. Adaptive management strategies will need to be devised that are robust and flexible enough to address climate change.

Most of the strategies, policies and tools necessary to manage water resources in the context of climate change have probably already been identified. Incorporation of climate change into New Mexico's water planning may require new modeling and scenarios, and may lead to adjusted priorities and revised timelines, including acceleration of "no regrets" strategies that will also ameliorate the other pressures on the State's water resources.

The State Water Plan (SWP) and many of the State's regional plans already provide a policy framework in which to address climate variability and incorporate many of the policies and strategies that need to be re-evaluated in the context of climate change. Mainstreaming climate vulnerabilities and adaptation strategies into water resource management will be required for comprehensive planning for sustainable development. While the literature on adaptation strategies is still quite limited, there are a variety of recommendations that include both new and revised components of strategic plans and appropriate management strategies. The report outlines some of these as a starting point for discussion of New Mexico's options for addressing climate change:

1. Strategic planning within all water-related plans that includes climate change scenarios while recognizing the uncertainties inherent in these predictions and maintaining flexibility within the planning environment to accommodate new modeling and data as it becomes available. Good strategic planning will require:
   a. improved federal and state water data gathering activities to support sound decision-making;
   b. increased transdisciplinary and collaborative stakeholder participation in planning and strategy design; and
   c. integrated regional water planning.

2. Highly adaptive management capacity at the watershed scale with particular attention to rangelands, agricultural systems, and aquatic ecosystems.

3. Assessing infrastructure vulnerabilities and capacities; improving existing infrastructure and management systems; expanding water supply through new technologies; and developing new approaches to storage.

4. Enhanced demand management, conservation and efficiency measures, with special attention to the water/energy nexus.

5. Addressing statutory, regulatory and institutional barriers.

6. Addressing the role of climate change in meeting the economic, social and environmental goals of sustainable development.

Climate change will likely have a significant impact on the availability of and demand for New Mexico's water during the next century. The key to successful adaptation is a robust planning structure that incorporates highly certain predictions (such as temperature increases) as well as less certain forecasts (such as precipitation changes) into scenarios that can direct implementation of flexible management strategies. The State Water Plan (SWP) and the regional plans provide a policy framework to which climate change can be added as an additional pressure, albeit a potentially more threatening one. Doing so will better position the State's water resource managers to meet objectives that might otherwise be compromised by changing climatic conditions, while waiting for improved climate predictions may compromise the State's ability to anticipate and capture potential benefits and avoid potential negative impacts.

Adapting to climate change will not be a smooth process and will require multiple management tactics rather than a one-time solution. Given the latest scientific research and modeling on the impacts of climate change, New Mexico could gain substantial benefits from anticipatory stoking of its water management toolbox with proactive policies and clearly beneficial "no regrets" strategies that also alleviate the additional pressures to the State's water resources.

> ***"In the Southwest, water is absolutely essential to our quality of life and our economy. Addressing climate change now, before it is too late, is the responsible thing to do to protect our water supplies for future generations."***
>
> ***Governor Bill Richardson***

I. GOALS, OBJECTIVES, SCOPE AND LIMITATIONS OF THIS REPORT

a) Introduction

Governor Bill Richardson has implemented an aggressive climate change initiative for New Mexico. His Executive Order 2005-033 [www.governor. state.nm.us/orders/2005/EO_2005_033] directed that the New Mexico Environment Department (NMED) provide a report on the impacts of global warming on New Mexico by December 31, 2005. That report is available at www.nmenv.state.nm.us/aqb/cc/Potential_Effects_Climate_Change. The E.O. also calls for a Climate Change Advisory Group (CCAG) to develop a comprehensive program to identify sources and decrease New Mexico's contribution to emissions of greenhouse gases. That will be completed by the end of 2006, and further information about that process can be found at www.nmclimatechange.us.

Recognizing that the biggest impact of climate change on New Mexico will be its affect on the State's water resources, the E.O. also directed:

> **"The Office of the State Engineer to work with other state agencies, with local and federal agencies, and with the State's research institutions to prepare an analysis of the impact of climate change on the State's water supply and ability to manage its water resources. A report summarizing findings shall be completed no later than July 2006."**

This report will therefore address water only, although it is important to consider it along with the NMED report which includes additional information about both water and ecosystem impacts that may not be covered in this document. It has also benefited from the input of an informal work group created to assist with its development. (See Appendix A) It was developed from information gleaned through published reports as well as informal discussions with water resource managers, planners, modelers, climate experts, and others contemplating the implications of climate change on water resources. As such, it represents a compilation of existing data and educated, scientific opinion on this issue. It does not purport to be an in-depth analysis of the issue, primarily because there is not a substantial amount of research specific to New Mexico available on the topic. Nor does it include new research. It is, instead, an initial review of the available information on the impact of climate change on New Mexico's water resources that can be expected based on existing research and analysis.

Global warming and climate change are increasingly understood because a growing number of researchers are contributing to the body of scientific knowledge and to the capacity for models to generate good predictions. However, with few exceptions, very little attention has been paid to the implications of climate change for water policy and management. The report's final section thus includes only a preliminary overview of those areas discussed in the existing literature in which adaptive management strategies will likely be required to limit the extent and severity of adverse and severe consequences from climate change. It is intended to create a framework for dialogue within which policy makers, water managers and the public can begin to incorporate climate change into strategic plans for the State's water future.

b) *Why is this an important issue?*

Water is so critical to the New Mexico's quality of life and economic vitality that any impacts to our water resources reverberate across the social, economic and environmental fabric of the State. The anticipated impact of climate change is particularly important since New Mexico is highly dependent on climate-sensitive natural resources (e.g. snowpack, streamflow, forests) and on natural-resource based economic activities (e.g. agriculture, recreation and tourism).

The pressures on water resources in New Mexico are already substantial.

> "In the Western United States, the availability of water has become a serious concern for many communities and rural areas. Near population centers, surface-water supplies are fully appropriated, and many communities are dependent upon ground water drawn from storage, which is an unsustainable strategy. Water of acceptable quality is increasingly hard to find because local sources are allocated to prior uses, depleted by overpumping, or diminished by drought stress. Some of the inherent characteristics of the West add complexity to the task of securing water supplies. The Western States, including the arid Southwest, have the most rapid population growth in the United States. The climate varies widely in the West, but it is best known for its low precipitation, aridity, and drought. There is evidence that the climate is warming, which will have consequences for Western water supplies, such as increased minimum streamflow and earlier snowmelt events in snow-dominated basins. The potential for departures from average climatic conditions threatens to disrupt society and local to regional economies."
> [Anderson, 2005]

In WATER 2025, the Bureau of Reclamation described the realities facing water managers in the Western U.S.: explosive population growth, existing water shortages that will (and already are) resulting in conflict, and aging water facilities that limit management options, noting that crisis management will not be enough to meet these challenges. WATER 2025 called for proactive management of scarce water resources and suggested guiding principles and key tools to address systemic water problems, many of which are relevant to the discussion of managing in the context of climate change. [USDOI, 2005]

The NEW MEXICO STATE WATER PLAN (SWP) created a framework for water management in the State. [www.ose.state.nm.us/water-info/NMWaterPlanning/state-water-plan] The policies and strategies that it established include many that will be useful in addressing climate change. The SWP already recognizes that New Mexico's climate varies a great deal. Climate change models indicate that such variation can be expected to continue, but that the rate and variation of these changes may be even less predictable and more extreme than in the recent past. The SWP includes multiple responses to climatic variability and change such as active water management, water conservation, urban growth management, development of new water supplies, and watershed and ecosystem protections, all of which often have many more general benefits and can promote longer-term economic and environmental stability for the State. [Meridith, 2002]

Climate change will thus present an additional challenge to management of the State's water resources. Along with population growth, economic development, existing climate variability, recurring drought, and the unpredictable impacts of international geopolitical events, it injects another layer of uncertainty and complexity into the arena in which strategic planning and water policy development occur. "By taking climate forecasts into account and adjusting operational practices to reflect potential conditions, resource managers are better positioned to meet resource management objectives that might otherwise be compromised as a result of different climate conditions. Climate forecasts may also enable managers to anticipate and capture the benefits associated with possible climate conditions. In both cases, the lead-time provided by the forecasts gives managers the opportunity to anticipate and plan for potential climate-induced changes." [Climate Impacts Group, 2005]

II. OBSERVED AND PREDICTED IMPACTS OF CLIMATE CHANGE ON NEW MEXICO'S WATER SUPPLIES

Thanks to the following individuals who contributed to this section: Prof. David Gutzler, University of New Mexico; Dr. Gregg Garfin, Climate Assessment for the Southwest, University of Arizona; Dr. Bernard Zak, Sandia National Laboratories.

a) Introduction

In the 20th Century global temperature increased by about 1°F, with much of the warming occurring after 1970 [IPCC, 2001]. An increasing body of evidence indicates that much of the increase in temperature is associated with anthropogenic inputs of carbon dioxide (CO_2), methane (CH_4), and other atmospheric greenhouse gases (henceforth GHGs). The GHGs are trace gases (present in small amounts in Earth's atmosphere) that actively absorb infrared radiation but are much less effective at absorbing solar radiation. Thus GHGs allow sunlight to pass through the atmosphere to the surface, but absorb and re-emit radiant heat emitted from the surface and "recycle" some of that heat back downward. Recycling of infrared radiation creates the "Greenhouse Effect" that keeps the Earth's surface significantly warmer than it would be in the absence of an atmosphere.

Although significant uncertainties remain concerning many aspects and predicted impacts of current climate change, there is no longer any serious debate about several fundamental results [IPCC, 2001; summarized by Gutzler, 2000]:

1) Earth's climate is warming rapidly, as can be seen in the worldwide retreat of glaciers, pack ice and snowfields during the 20th Century, continuing today.

2) Ice core records show that several principal atmospheric greenhouse gases are now present in concentrations higher than at any time in the last half-million years. The abrupt rise in the concentrations of these gases since the Industrial Revolution is due without doubt to human activities. The concentrations of each of these anthropogenic greenhouse gases continues to increase rapidly; in this century it seems inevitable that CO_2 will reach a concentration more than double its pre-industrial value.

3) The direct radiative effect of GHGs is very well understood. There is no doubt that the direct effect of increasing the atmospheric concentrations of GHGs is an increase in Earth's surface temperature.

Similar trends in temperature over the past few decades are clearly in evidence across New Mexico; indeed, warming trends across the American Southwest exceed global averages by about 50%. Since the 1960s, wintertime statewide average temperatures have increased by nearly 1.5°F (Fig. II-1).

It is important to keep in mind that the ongoing warming of global and regional climate is taking place in the context of shorter term weather and climate variability, as well as demographic factors that may increase our vulnerability to climate change. The American Southwest is subject to recurring severe multi-year drought episodes, which occur on average several times per century, as determined from tree ring records spanning the last thousand years (Fig. II-4). These pronounced drought episodes, which seem to be a natural component of regional climate, are expected to continue as the climate warms. Meanwhile human population is increasing rapidly in New Mexico, and across the southwestern U.S. and northern Mexico, despite the limited water supply in this arid region.

b) Overview of climate trends and predictions for New Mexico and the Southwest

In the American Southwest, the impacts of climate variations on water supplies are easily recognizable by simply observing snowpack, reservoir and stream flow levels. Both Global Climate Models (GCMs) and historical trends in temperature, precipitation, and snowpack can be used to assess the recent and potential future effects of climate change on water resources across the Southwest and New Mexico. GCMs indicate that by the end of this century, the American Southwest, and more specifically New Mexico, can expect a significant increase in temperature, resulting in a decrease in snowpack. Precipitation predictions are far less certain, as will be shown in sections II(d) and II(e). The models suggest that even moderate increases in precipitation would not offset the negative impacts to the water supply caused by increases in temperature. Predicted changes in climate variability could also result in more frequent and extreme flooding [Nash and Gleick, 1993].

i) Temperature

Climate models predict that increases in temperature in the 21st Century will be greater in the Southwest than the global average, as part of a general tendency for continental interiors to warm up more than oceans or coastal regions [IPCC, 2001]. In the northern part of New Mexico, the largest increases in temperatures over the past several decades have occurred in the winter months, resulting in recent annual average temperatures more than 2º F above mid-20th Century values [Figure II-1]. Recent model simulations suggest accelerated summertime warming in the future [Figs. II-8 and II-11], as will be described below.

ii) Snowpack

Climate models predict a trend toward higher freezing altitude and reduction in Western snowpack [Fig. II-2] over the coming decades as a result of rising temperatures [U.S. GCIRO, 2005]. The anticipated higher temperatures discussed above will have several major effects: delay in the arrival of the snow season, acceleration of spring snowmelt, and therefore a shorter snow season, leading to rapid and earlier seasonal runoff [Gleick, 2000]. Annual average temperatures have been rising in the mountainous areas of New Mexico during the winter and early spring [Fig. II-1], which supports model-based projections that snowfall will begin later and total snowfall will decrease, even if winter precipitation stays the same or increases [Lettenmaier, 2004].

Snowpack has been below average for 11 of the past 16 years in the Colorado River Basin and 10 of the past 16 in the Rio Grande Basin [RMCO, 2005]. After one winter of exceptionally abundant snowpack in 2004-05, this trend continued in the winter of 2005-06. Snowfall in New Mexico was far below average last winter and snowpack observations ranged from 40% of average in the upper Rio Chama basin to less than 10% of average over most of the state [SWCO, 2006].

The recent observed decrease in snowpack in the Southwest has coincided with the warming trend. Climate models predict that snowpack in the Southern Rocky Mountains will continue to decline through the 21st Century [Figs. II-3 and II-13]. Increasing temperatures may deplete the water resources in the Colorado River Basin by as much as 40% by the end of the century [Lettenmaier, 2004].

iii) Precipitation

Climate models predict a marked decrease during the 21st Century in the ratio of rain to snow in winter precipitation [IPCC, 2001]. The largest percentage increases in precipitation falling as rain are likely to be in the Southwestern U.S. [Felzer and Heard, 1999]. Recent model simulations also predict a decline in total winter precipitation across New Mexico (Figs. II-9 and II-12), but large uncertainties surround these precipitation predictions. Other models show modest increases in winter precipitation. However a recent study concluded that a 7°F increase in temperature in the Colorado River Basin would require precipitation increases of 15-20% above current averages to mitigate the decrease in flows experienced from evaporative losses [Nash and Gleick, 1993]. Additional research has also shown that increases in precipitation along with increased temperatures can result in decreases in runoff [Wolock and McCabe, 1999].

iv) Drought

Increasing temperatures, earlier snow melt, and decreasing soil moisture lead to an increase in summertime evaporation, thereby decreasing recycled moisture availability and creating a cycle that perpetuates the “increased intensity, frequency and duration of drought” [WCRP, 2003]. Tree ring-based reconstructions of western droughts over the last millennium show a correlation between warm temperatures and drought, indicating that long-term warming trends could lead to extreme aridity over the western United States [Cook et.al., 2004]. Another reconstruction dating back to 1512 indicates that long-term annual flow in the Colorado River was likely 10% less than the average annual flows measured from1906 to 2000 [Lettenmaier, 2004].

A representative precipitation history derived from old trees in northern New Mexico [Fig. II-4] shows that recent decades (light blue and green lines) have been relatively wet compared to the long term climatic average (black line). Note that the 1950s drought (red line), the most severe drought in New Mexico in the instrumental record, shows up as a severe episode but is by no means the worst drought in the past 1000 years. This long record, like other reconstructions from different parts of the Southwest, shows that intermittent decade (or longer) droughts have been a recurring feature of Southwest climate for many centuries. These droughts are currently not predictable, but New Mexicans should assume that severe droughts (like the 1950s, or worse) will continue to occur in the future.

v) Flood events

Warming trends will result in shifts and changes in the magnitude of runoff peaks that depend on overall precipitation [Gleick, 2000]. As discussed above, warming at high elevations will decrease winter snowfall and snowpack, increase winter rainfall, and accelerate spring snowmelt, causing probable increases in winter runoff and decreases in summer streamflow [Gleick, 2000]. Increases in summer surface temperatures will likely result in reduced atmospheric stability, increased convection, and a more vigorous hydrologic cycle, resulting in a climate conducive to more intense (but possibly less frequent) storms [Carnell and Senior 1998, Hayden 1999], thereby leading to an increase in flood events. Springtime peak flows could increase significantly and flood events could be earlier and more extreme.

c) Global Climate Model (GCM) Predictions

GCMs of several kinds have been developed over the past half century to aid in evaluating what the impacts would be on future climate of various societal choices regarding the use of fossil fuels. The starting point for the use of such models is the definition of "scenarios" for carbon dioxide and other GHG emissions -- effectively, different guesses as to how society might respond to trends in the availability of current fuels (e.g. petroleum) and the potential threat of climate change. The Intergovernmental Panel on Climate Change (IPCC) began its work in 1988, and came out with its first assessment report in 1990 [IPCC, 1990]. In support of its first report, the IPCC defined 6 such emissions scenarios. In support of its third assessment report in 2001, IPCC expanded the number of scenarios considered to 40, categorized by different assumptions about global economic and population growth, as well as global energy policy. Of these, 6 "marker scenarios" were chosen by the IPCC to represent the whole range of potential futures [IPCC, 2001].

Coupled ocean-atmosphere GCMs (CGCMs) running on fast supercomputers represent the state of the art for climate modeling science. Within this category of GCM, more than a dozen models exist, developed and used by various research groups around the world [Meehl et al., 2005]. A suite of such models yielded the results presented in Section II(d). Although they agree on warming in the presence of increasing GHG, each model predicts the evolution of global climate a little differently even when forced by the same GHG emissions scenario. To go from any one of these global simulations to useful regional predictions that take topography into account, it's necessary to couple CGCM results to a higher resolution regional climate model. Results from such a simulation are described in Section II(e).

In considering the effect of climate change on water resources in New Mexico, if one were to follow the IPCC approach, one would run a suite of different CGCMs on the selected IPCC marker scenarios, and couple each run to one (or more) regional model(s). The results could reasonably be expected to span the range of future climate uncertainty. That's well beyond the scope of the present study. However, there was a recent model-based study of the impact of climate change on water resources in the West that took a more limited but nonetheless in depth look at the issue [Barrett, 2004]. Although it did not focus specifically on New Mexico, the state was included in the modeling domain so useful information can be gleaned from that study. Called the Accelerated Climate Prediction Initiative (ACPI), the Jan-Feb 2004 issue of the journal *Climatic Change* was dedicated to ACPI results.

In ACPI, a single GCM (the NCAR/DOE Parallel Climate Model [PCM]) was forced by a single emissions scenario, a "Business as Usual" (BAU) scenario, for the 21st century. The BAU scenario was developed before the IPCC 2001 scenarios, but it's close to the mean of emissions assumed in those scenarios. The PCM results were "downscaled" to the western region [Leung et al., 2004] using the Penn State/NCAR (National Center for Atmospheric Research) mesoscale model (MM5). For selected river systems, the results were then used to drive the Variable Infiltration Capacity (VIC) macroscale hydrology model to produce stream flow sequences. For the Colorado River basin (including all of Arizona and parts of California, Nevada, Utah, Wyoming, Colorado and New Mexico), annual predicted runoff was 10% lower for simulated 1995 conditions than for historical averages for 1950-1999. For the periods 2010-2039, 2040-2069 and 2070-2098, simulated annual runoff was 14%, 18% and 17% lower than the historical average [Christiansen et al., 2004]. However, because of the timing of the melt (earlier in the spring) and increased evaporation due to higher temperatures, the Colorado River Model used by the USGS predicts that the cumulative total basin storage in reservoirs for these three periods could be reduced by 36%, 32% and 40% respectively [Figure II-5a].

A very similar approach could be used for the Rio Grande using the PCM and MM5 model runs already done, applying the VIC hydrologic model to this different region, and interpreting the results using a Rio Grande rather than a Colorado River model. Such an effort would be far more relevant to New Mexico. In the absence of such research, however, the work already done on the Colorado is at least indicative. It should be pointed out that the average predictions for the focus periods give no indication of the extremes that might occur. Thus droughts could occur that are far more serious than the averages would suggest. Nor do the results bar extremes on the other end of the spectrum -- floods. Some indication of the range of possible variation can be obtained from the historical record. Between 1906 and 2000, Colorado River annual flow varied between 5.5 million acre feet (MAF) and 25.2 MAF, with an average of 15.3 MAF [Figure II-5b]. Longer term paleoclimate records suggest that the range of possible variation could be much greater yet [Woodhouse et al., 2006].

This section wouldn't be complete without some reference to a climate change scenario which is very different from that discussed above. Model studies have indicated that increasing warming could cause the global ocean currents to reach a "tipping point," and quite suddenly (within a decade or so) cause a drastic change in global climate. The paleoclimatic records from Greenland and Antarctic ice cores indicate that such "flips" have occurred more than 20 times during the last 100,000 years [NRC, 2002]. There is at most an ambiguous indication that such a flip might occur within the planning horizon for water resources in New Mexico [Shiermeier, 2006]. Much less is known about the climate and its potential impact on water resources that might result from such a flip than from the warming scenarios discussed here.

d) Climate predictions for New Mexico using IPCC global climate models

Climate predictions using GCMs from the forthcoming IPCC AR4 assessment [http://www.ipcc.ch] were used to examine potential changes in temperature and precipitation in New Mexico in the 21st century. The models used the Special Report on Emissions Scenarios (SRES) A1B GHG emissions scenario [Nakicenovic et al. 2000; http://www.grida.no/climate/ipcc/emission/index.htm]. The A1B scenario assumes a future world of very rapid economic growth; global population that peaks in mid-century (at approximately 9 billion) and declines thereafter; and rapid introduction of new and more efficient technologies. The A1B scenario has total CO_2 emissions peaking at more than 16 gigatonnes/year (Gt/yr) at mid-century, declining somewhat by the end of the century (Fig. II-6). This results in more than a doubling of pre-industrial atmospheric CO_2 levels by the end of the century. The model experiments included radiative forcing by natural factors, such as changes in solar irradiance and volcanic eruptions, in addition to human-influenced factors such as changes in greenhouse gases and aerosols. The human-influenced factors start with observed data and vary through the course of the 21st century based on the assumptions of the aforementioned A1B scenario.

The average of eighteen GCMs forced by the A1B GHG scenario was used in the projections presented here. As discussed in the previous section, there is no way of determining which models best represent the future. The use of a broad average of many GCMs preserves the richness of variability in the complete suite of models, rather than relying on a subset of models that might show faithful representation of present conditions. The GCMs provide projections at rather coarse spatial resolution, depending on the individual model. Spatial resolutions ranged from 1°-3° in latitude and longitude, or approximately 275 km (170 mi.) per side of grid box at 45°N. The entire state of New Mexico is covered by no more than a dozen (often fewer) grid cells in these models.

Averaging the projections required harmonizing the variety of spatial resolutions in the GCMs by downscaling (statistically interpolating) the data to NOAA climate divisions (http://www.cdc.noaa.gov/USclimate/map.html) for the entire United States. Data were kindly provided by Martin Hoerling and Jon Eischeid of the NOAA Earth System Research Laboratory. The climate division data were then combined to create New Mexico statewide temperature and precipitation averages. Specifics regarding the fourth assessment models and projections can be obtained from the Program for Climate Model Diagnosis and Intercomparison (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php).

The 18-GCM New Mexico statewide average temperature and precipitation projections (henceforth, *GCM statewide averages*) exhibit some biases compared to observed climate records (Table II-1). The GCM statewide precipitation averages are greater than observed overall, particularly in winter. Water year temperatures are slightly warmer, due to relatively high summer temperatures, despite cooler than observed winter temperatures. The model predictions (below) are presented in comparison to the benchmark of the GCM statewide 1971-2000 averages; however, the aforementioned biases indicate model uncertainties that must be taken into consideration. Moreover, as has been shown by others, GCM temperature projections show greater consistency than precipitation projections (Cayan et al., 2006; Dettinger, 2005).

The GCM NM statewide averages suggest substantial increases in temperature by the end of the century (Table II-2), particularly in summer. Projected GCM NM statewide average temperature increases of over 3°C (more than 5°F) are far greater than temperature increases experienced during the period of instrumental record [Fig. II-1b]. Figures II-7 and II-8 show steady long-term upward trends in annual, winter, and summer temperatures. Trends of as little as 0.04°C/year in summer add up to a considerable overall warming by the end of the 21st century. Increases in summer temperature may impact evapotranspiration and soil moisture, as well as energy demand for cooling. The impacts of recurring drought will undoubtedly be exacerbated by temperature increases, as demonstrated during the relatively warm drought of the late 20th century [e.g., Breshears et al., 2005].

Annual precipitation, though characterized by greater uncertainty, is projected to decline by 4.8% (29.3 mm) per year by the end of the 21st century (Table II-2; Fig. II-9). Increases in summer precipitation (up to several mm/yr by mid-century) are more than compensated for by decreases in winter precipitation (and presumably spring and fall precipitation). Precipitation projections for both winter and summer (Fig. II-10) show multi-decadal fluctuations characteristic of ocean-driven variability in the instrumental and paleoclimate records [Brown and Comrie, 2004; Gutzler et al., 2002; Grissino-Mayer and Swetnam, 2000; Ni et al., 2002]. Even given the high uncertainty in precipitation projections, GCM NM statewide temperature changes are probably substantial enough to have a bearing on the overall composition of winter precipitation – snow versus rain. As in other parts of the West, increasing temperatures may also shift the peak of snowmelt-driven streamflow to earlier in the year, with ramifications for the reliability of water resources [Stewart et al., 2005; Jain et.al., 2005].

The aforementioned temperature projections, though expressed at a coarse spatial scale, are reasonably compatible with estimates from the National Assessment of the U.S. Global Change Research Program [USGCRP, 2000]. However, the overall decrease in annual precipitation [Fig. II-9] is at odds with results from the two models selected by the USGCRP. The steep decline in winter precipitation, especially toward the end of the 21st century [Fig. II-10] may reflect a shift in the El Niño-Southern Oscillation phenomenon, due to GHG-induced perturbations in ocean-atmosphere dynamics [e.g., Vecchi et al. 2006]; or it may indicate a tendency for a few overly dry models (e.g., the Australian model; Ron Neilson [Oregon State University] personal communication) to pull the 18-model average down. Given the poor representation of North American monsoon processes in most GCMs [Gutzler et al., 2005], the precipitation projections must be viewed with caution.

e) Climate predictions for New Mexico using a regional climate model

The global models used in the previous section provide large-scale guidance for potential climate change based on a particular choice of future GHG forcing. As noted, global models typically feature relatively coarse horizontal resolution. Section II(c) outlined a strategy for using higher resolution regional models to improve the description of climate change over limited areas. Diffenbaugh et al. [2005] carried out a climate change simulation by embedding such a regional model, called RegCM3, within the NASA FV-GCM global model [Atlas et al., 2005].

This simulation was forced by a different GHG emissions scenario, denoted A2 in Fig. II-6. The A2 and A1B scenarios differ primarily in emissions late in the 21st Century. Of course, both of these scenarios represent guesses and many other scenarios are possible, as discussed in Section II(c). All realistic scenarios include significant increases in GHG concentrations in this century, so the principal qualitative difference in the climate change results is simply timing. Scenarios with higher GHG emissions levels generate faster warming trends and more severe climate changes. Therefore the selection of an emissions scenario mostly affects the dates by which a certain level of warming (or snowpack decline, etc.) is reached.

In the Diffenbaugh et al. [2005] simulation, RegCM3 covers the contiguous 48 United States with a horizontal resolution of 25 km. RegCM3 was run for two time periods: 1961-1985, to represent recent climate, and 2071-2095, to represent climate at the end of the 21st Century associated with the A2 GHG scenario. Selected RegCM3 output fields across New Mexico and southern Colorado for these two time periods were kindly provided by Noah Diffenbaugh of Purdue University. Each of the plots shown here depicts the simulated difference between recent climate (1961-1985) and late 21st Century climate (2071-2095).

Fig II-11 shows the change in temperature across the state of New Mexico for

(a) annual mean conditions,

(b) the summer season (June-August), and

(c) the winter season (December-February).

In this model, the A2 scenario generates annual temperature change between 3°C and 5°C (Fig. II-11a), with the magnitude of temperature change increasing inland (toward the north). Recall that observed 20th Century temperature change across the state since the 1960s has been about 1.5°F (Figs. II-1 and II-2), which is somewhat less than 1°C. Therefore this simulation indicates that the relatively rapid warming observed over the past several decades will continue at a greatly accelerated rate during the 21st Century. Spring season results are similar to winter, and fall season is similar to summer (these results not shown).

Precipitation changes for the annual mean, summer and winter (Fig. II-12) are modest compared to temperature changes. The annual average change is generally not statistically significant (Fig. II-12a). The near-zero annual mean change in this simulation results from a slight decrease in summer rainfall (Fig. II-12b) and an offsetting increase in winter precipitation (Fig. II-12c). Other model simulations of 21st Century climate show precipitation changes of different sign, as discussed in Section II(d). Thus, the most predictable climate change in New Mexico forced by increasing GHG is a strong temperature trend toward warmer conditions, not a systematic change in total precipitation one way or another.

As shown in Fig. II-11b, the greatest warming in this simulation occurs in the summer season (consistent with the global model predictions shown in Fig. II-8), with temperature change exceeding 5°C in northeastern New Mexico. Winter warming is considerably less (between 2° and 4°C in Fig. II-11c), with greatest warming in northwestern New Mexico. One consequence of pronounced summer temperature increase is an increase in both the magnitude and length of extreme heat waves, as described by Diffenbaugh et al. [2005]. In this report we emphasize the effects of climate change on water resources, assuming broadly that precipitation variability from year to year is similar to the current climate, including intermittent drought episodes. Water resources in New Mexico would be greatly affected by the warming trend illustrated in these RegCM3 (and other) simulations, even in the absence of significant precipitation change, because more winter precipitation falls as rain instead of snow, and soil moisture decreases, especially in spring and summer.

The magnitude of winter warming has profound consequences for snowpack throughout the interior of western North America. Fig. II-13 shows the change in snowpack (expressed in mm H_2O content, commonly referred to as "Snow Water Equivalent" or SWE in observed data) for:

(a) New Mexico, March 1 average,

(b) New Mexico, April 1 average, and

(c) eastern Utah/western Colorado, April 1 average.

The current average date of maximum snowpack in southern New Mexico is around March 1, while snowpack in northern New Mexico and southern Colorado typically reaches its maximum around April 1. Examination of the mean snowpack fields from the model (not shown here) indicate that the solid blue color across New Mexico in climate change panels (a) and (b) can be interpreted to mean that spring snowpack is, on average, nonexistent south of about 36°N in the late 21st Century. In other words, the late 21st Century climate in this simulation includes no sustained snowpack south of Santa Fe and the Sangre de Cristo range.

Snowpack remains in far northern New Mexico and southern Colorado (the headwaters region of the Rio Grande), but is greatly reduced in mass by the end of this century. The April 1 climate change in Fig. II-13c shows reductions in April 1 SWE of 50-200 mm H_2O, compared to an average in the 1961-1985 simulation of 100-300 mm H_2O across the San Juan mountains, i.e. a decrease in water mass between one-third and one-half. Some of this decrease results from earlier snowmelt, and some from higher freezing altitude (snow line) during the winter. Spring runoff into rivers and reservoirs is likely to be drastically reduced by the late 21st Century.

Soil moisture changes are most pronounced in the spring (March-May) season, shown in Fig. II-14. The largest changes are seen in northwest New Mexico, where the upper layer soil moisture content decreases by 5 mm H_2O or more, a decrease of about 20% relative to the 1961-1985 simulation. This change is associated with the decrease in snowpack in the springtime. Soil moisture in the summer season also decreases but less in absolute terms, because soils are dry then even in the current climate.

Evaporation from the surface decreases in the summer season (June-August) in this simulation, shown in Fig. II-15. The red colors represent increased rates of evapotranspiration (ET) of 0.5 mm/d, which is a reduction of 25% or more relative to current ET rates simulated by the model. This is the result of drier soils and less summer rainfall, and (as noted by Diffenbaugh et al. [2005]) produces a positive feedback on summer temperature increases by reducing the surface cooling effect of evaporation. Interpretation of evaporation changes in this model must be tempered with a significant caveat: the model does not include interactive vegetation, so long-term changes in vegetation that may result from significant climate change are not included in the results [Diffenbaugh et al., 2005].

There are several points worth noting concerning the evaporation changes simulated by the model. First, as discussed above, reduced summer ET simulated by the model is associated with drier surface conditions. Where the surface is not dry (such as the water surface of a reservoir), evaporation rates are certain to *increase*, not decrease, under the 21st Century climatic conditions simulated by this model. Thus depletion of water resources by evaporation from reservoirs would increase. Second, the change in average climate simulated here would greatly increase New Mexico's vulnerability to recurring drought episodes. Drought conditions (such as the state experienced in the winter and spring of 2006) exacerbate the surface dryness that RegCM3 simulates as a mean condition in the late 21st Century. Warmer temperatures, more extreme heat waves, and a drier surface would make drought episodes more extreme in the changed climate.

The regional climate changes simulated by RegCM3, if realized, would have profound, seasonally varying consequences for the hydrologic cycle across New

Mexico. In the cold season (winter and spring), snowpack would be reduced drastically even if total precipitation stays the same or increases somewhat -- and model predictions include the possibility of a reduction in winter precipitation. In the warm season, warmer temperature and drier land surface conditions would raise evaporation rates off open water surfaces and increase vulnerability to drought cycles. These statements remain valid despite continuing uncertainty concerning long-term climatic trends in total precipitation rates in both winter and summer.

Acknowledgements. Jon Eischeid and Martin Hoerling (NOAA Earth System Research Laboratory) provided the IPCC projection data (Fig. II-7 to II-10) and shared insights regarding global climate model output. Ben Crawford (Climate Assessment for the Southwest, University of Arizona), put together several of the IPCC projection figures. Noah Diffenbaugh (Purdue University) generously provided regional model projection figures (Figs. II-11 to II-15).

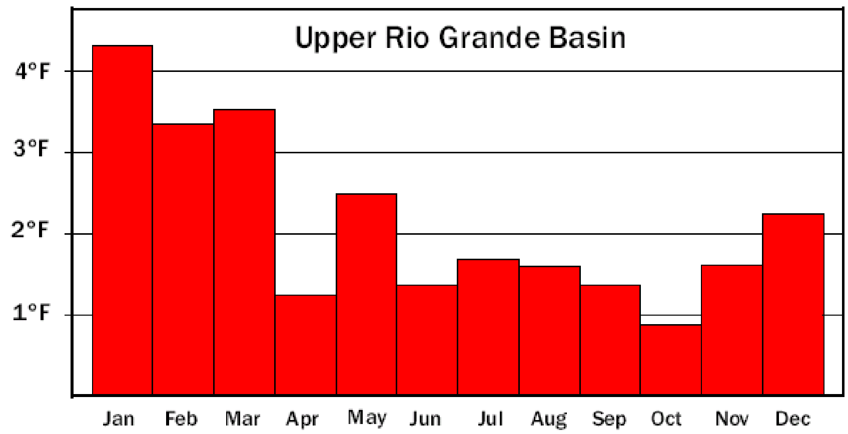
Table II-1. Differences between observed (Obs.) and 18-model average temperature (TEM) and precipitation (PPT) for the water year (WY; October-September), winter (DJF; December-February), and summer (JJA; June-August), for the period 1971-2000.

Variable	Obs (in./°F)	Obs (mm/°C)	Model (mm/°C)	Bias (mm/°C)	Bias (in./°F)
WY PPT	14.5 in.	368.6 mm	601.0 mm	232.4 mm	9.1 in.
WY TEM	53.5°F	11.9 C	12.2°C	0.3°C	0.5°F
DJF PPT	2.0 in.	51.8 mm	127.9 mm	76.1 mm	3.0 in.
DJF TEM	36.1°F	2.3°C	0.7°C	-1.6°C	-2.9°F
JJA PPT	6.1 in.	156.0 mm	191.4 mm	35.4 mm	1.4 in.
JJA TEM	71.4 F	21.9°C	24.1°C	2.2 C	4.0°F

Table II-2. Changes in temperature and precipitation between the 30-year model reference period (1971-2000) and projections for 30-year periods.

	1971-2000	2001-2030 (change)	2031-2060 (change)	2061-2090 (change)
WY TEM (°C)	12.2	13.1 (+0.9)	14.3 (+2.1)	15.5 (+3.3)
DJF TEM (°C)	0.6	1.4 (+0.8)	2.3 (+1.7)	3.4 (+2.8)
JJA TEM (°C)	24.1	25.2 (+1.1)	26.5 (+2.4)	27.8 (+3.7)
WY PPT (mm)	601.0	590.0 (-11.0)	589.4 (-11.6)	571.7 (-29.3)
DJF PPT (mm)	127.9	127.0 (-0.9)	125.8 (-2.1)	122.4 (-5.5)
JJA PPT (mm)	191.4	189.6 (-1.8)	195.5 (+4.1)	193.0 (+1.6)

Figure II-1a: Average Monthly Temperatures in 1995-2004 in the Upper Rio Grande Basin, compared to 1961-1990 average values. [RMCO 2005]



Data from the climate division series, National Oceanic and Atmospheric Administration. Analysis by the Rocky Mountain Climate Organization. Historical average monthly temperatures are from the period 1961-1990.

Figure II-1b: Five-Year Average Temperatures, 1895 to 2004, compared to Historical Averages [RMCO 2005]

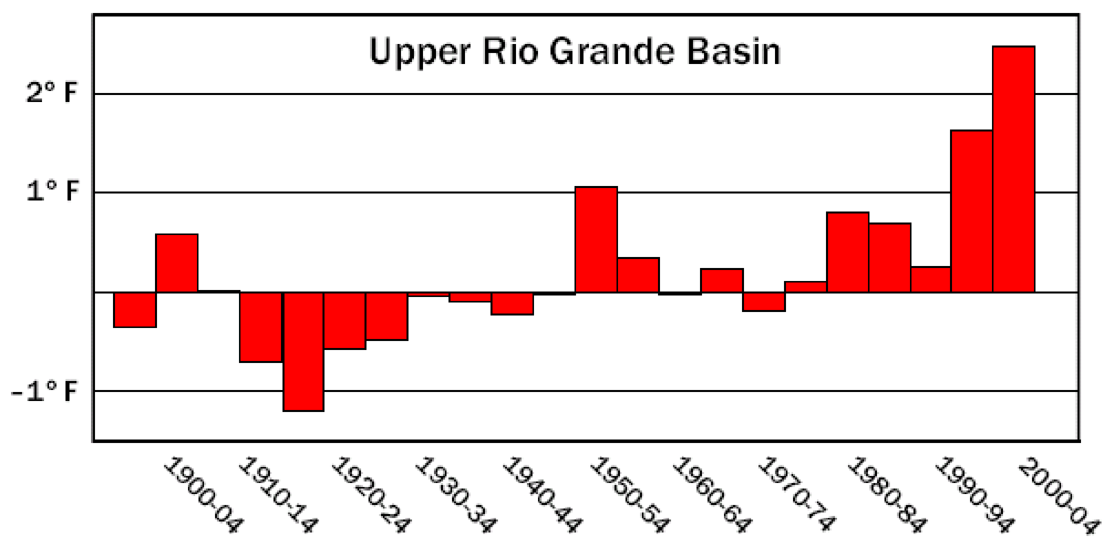


Figure II-2: Possible effects of warming on snowline in higher elevations [Gleick et al., 2000].

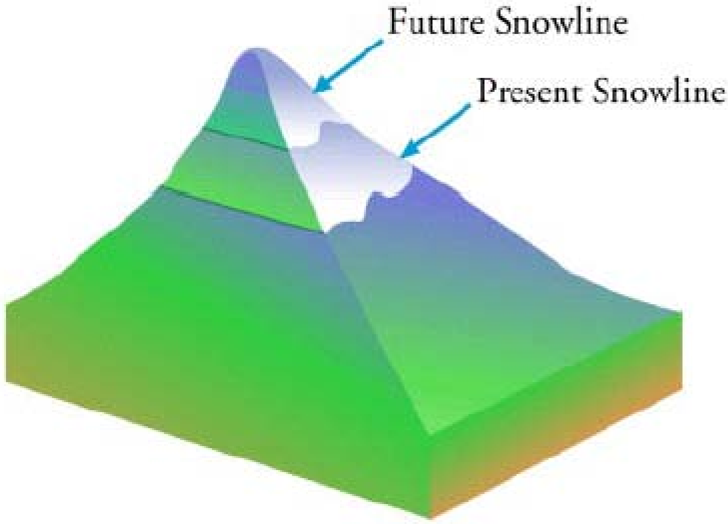


Figure II-3: Percentage change from the 1961-90 baseline in the April 1 snowpack in four areas of the western US as simulated for the 21st century by the Canadian and Hadley models. [USGCRP, 2000]

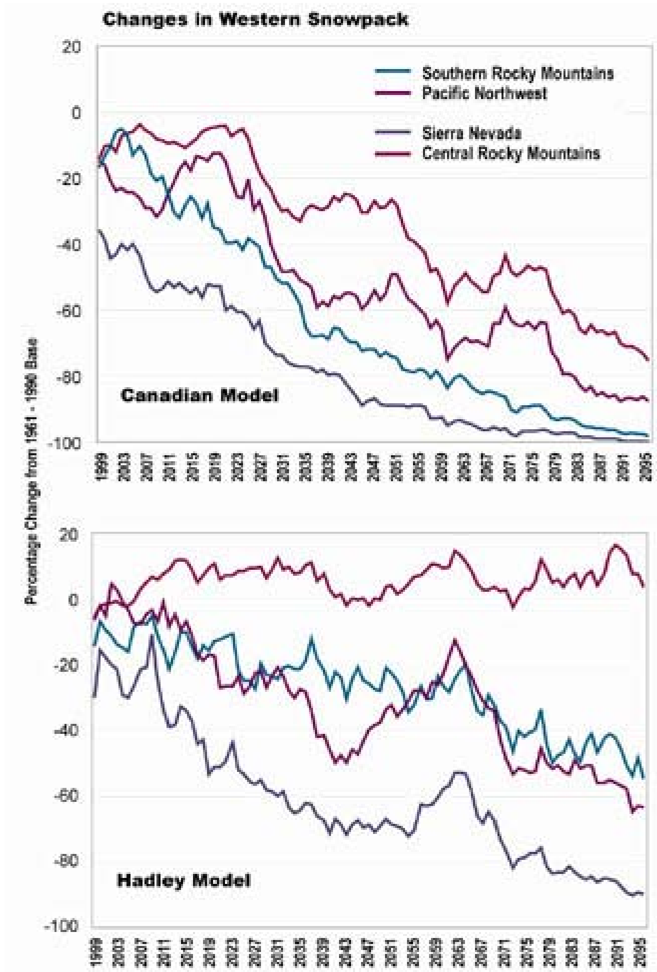


Figure II-4: Precipitation time series for the past millennium for New Mexico Climate Division 2 (north central New Mexico, including the upper Rio Grande Valley). The time series is based on tree ring data within Division 2, and values are expressed as percentage departures from the 1000-year average (thick black line). Average values for three recent decades -- 1983-1993 (a wet period), 1946-1956 (a dry period), and 1996-2006 (the most recent decade) -- are shown as light blue, red, and green lines, respectively.

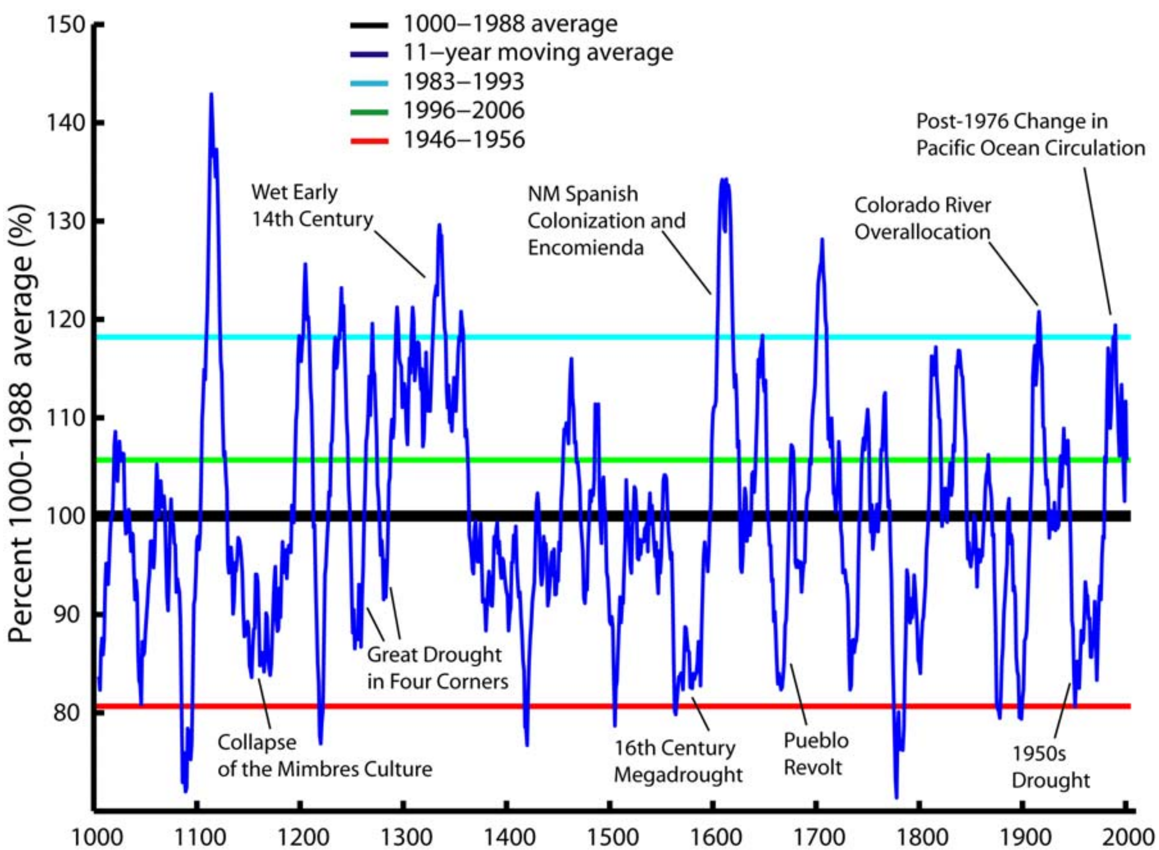


Figure II-5a: Projected changes in average total Colorado River Basin reservoir storage, for downscaled climate simulations of the U.S. Department of Energy/National Center for Atmospheric Research Parallel Climate Model (PCM) based on projected 'business-as-usual' (BAU) greenhouse gas emissions and a control climate simulation based on static 1995 greenhouse gas concentrations, and an ensemble of three 105-year future climate. Simulations for three time periods, and a comparison with observed historical (1950–1999) climate.

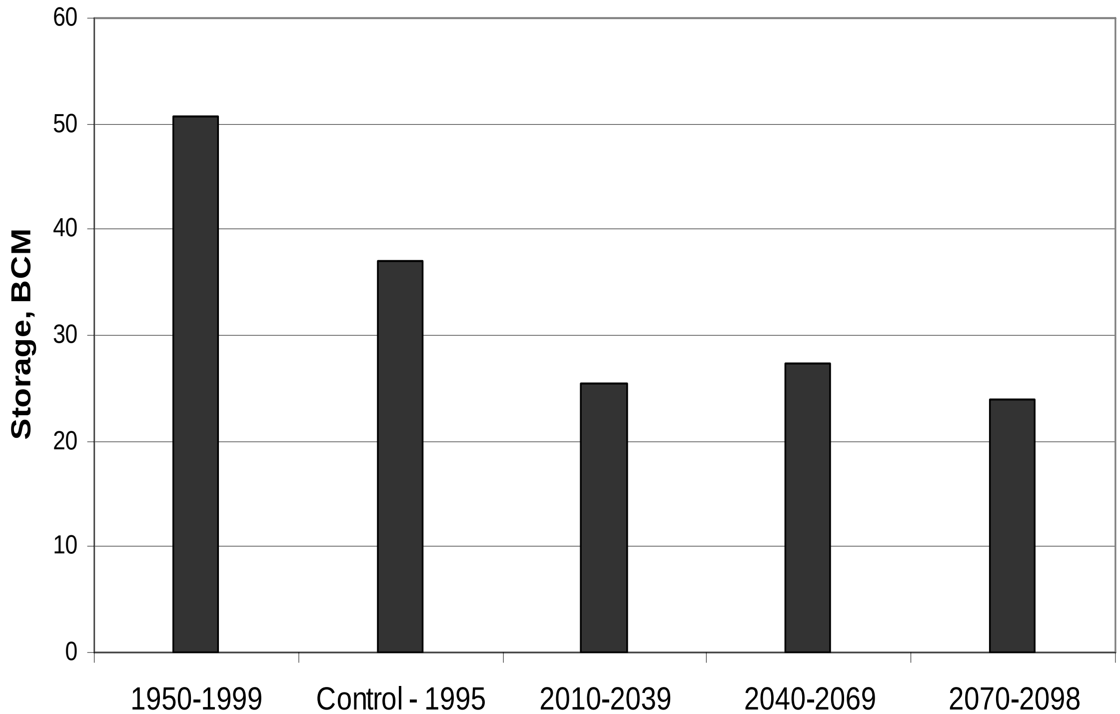


Figure II-5b: Colorado River Basin water year (October-September) annual flow, 1906-2000. Average flow for the period is 15.3 million acre-feet (MAF). The lowest flow in the record is 5.5 MAF in 1977 (Oct. 1976-Sept. 1977); the highest flow in the record is 25.2 MAF in 1984 (Oct. 1983-Sept. 1984). Data courtesy of Dave Meko (University of Arizona) and Jim Prairie (U.S. Bureau of Reclamation).

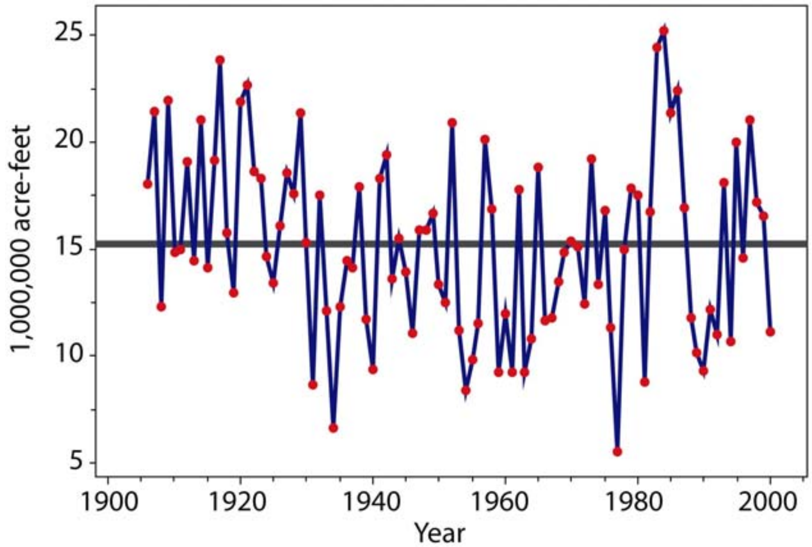


Figure II-6: IPCC Special Report on Emissions Scenarios CO_2 assumptions for the 21st century. The atmospheric CO_2 concentrations associated with particular emissions scenarios, shown in this plot, are generated by a carbon cycle model. SRES A1B (green line), the scenario used in IPCC 4th Assessment Report projections shown in this section, describes a future world of very rapid economic growth; global population that peaks in mid-century and declines thereafter; new and more efficient technologies are rapidly introduced. SRES A2 (red line), used in the regional model simulation described in section II(e), is similar during the first half of the 21st Century but assumes a higher emissions rate late in the century. Other scenarios (such as B1, the blue line shown here) provide different guesses for 21st Century GHG emissions. Still other, unrealistic scenarios (such as the orange curve assuming no increase at all in CO_2 concentration in the future) are developed by the IPCC for comparison purposes.

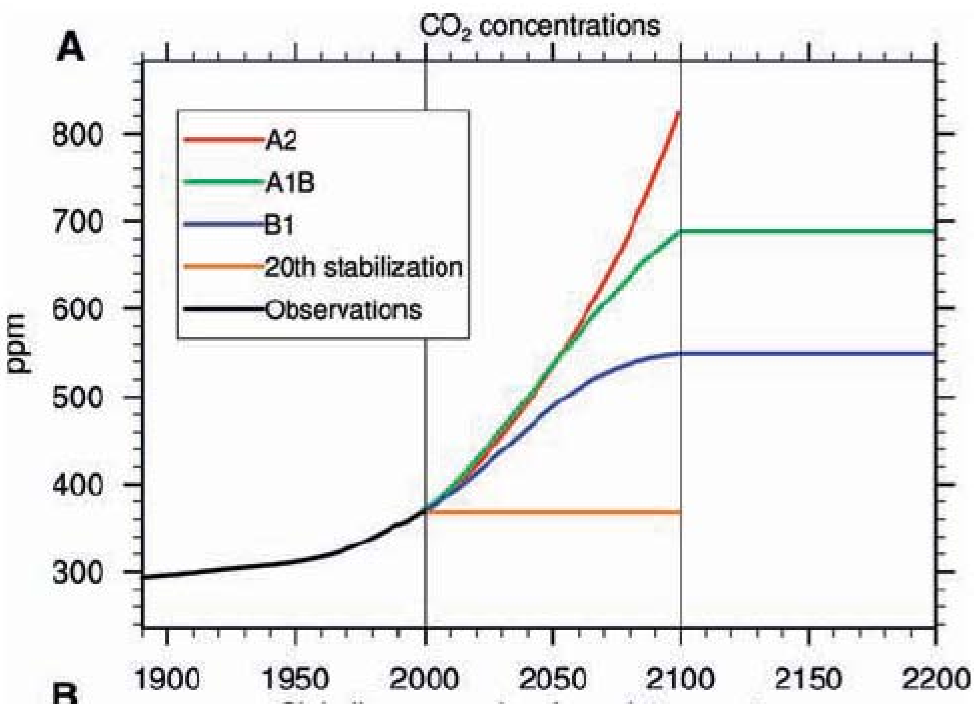


Figure II-7: New Mexico water year (October-September) annual temperature projections compared with model climatology (1971-2000).

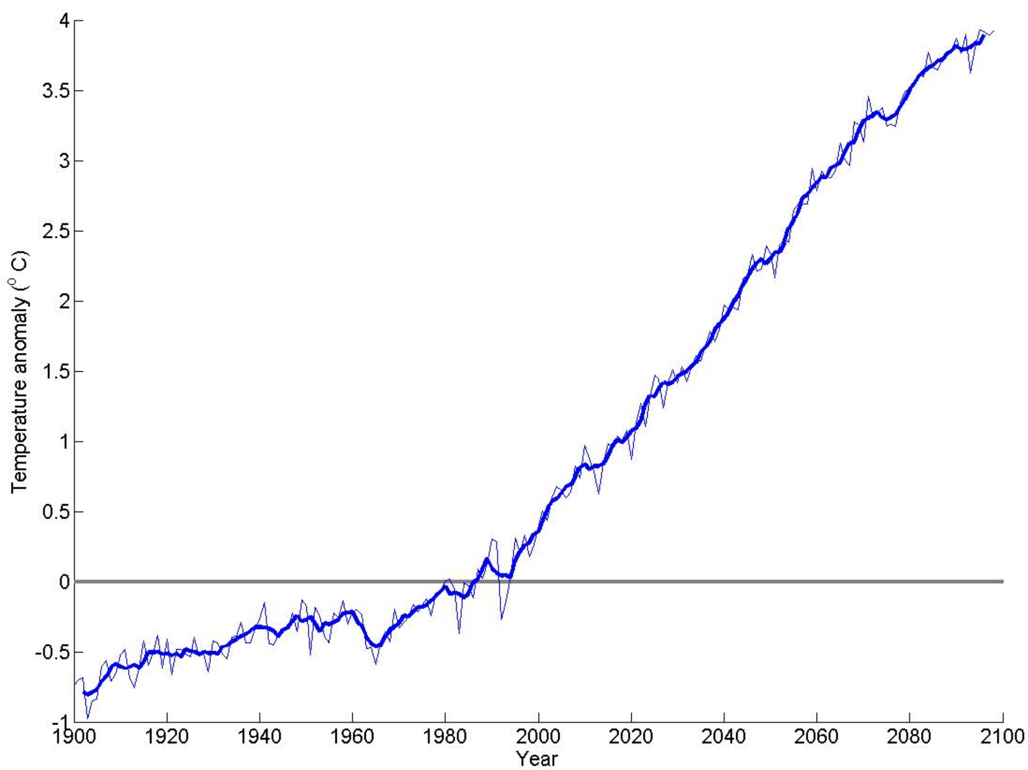


Figure II-8: Simulated New Mexico seasonal temperature changes in the 21st Century for summer (red line; June-August) and winter (blue line; December-February), compared with model climatology (1971-2000).

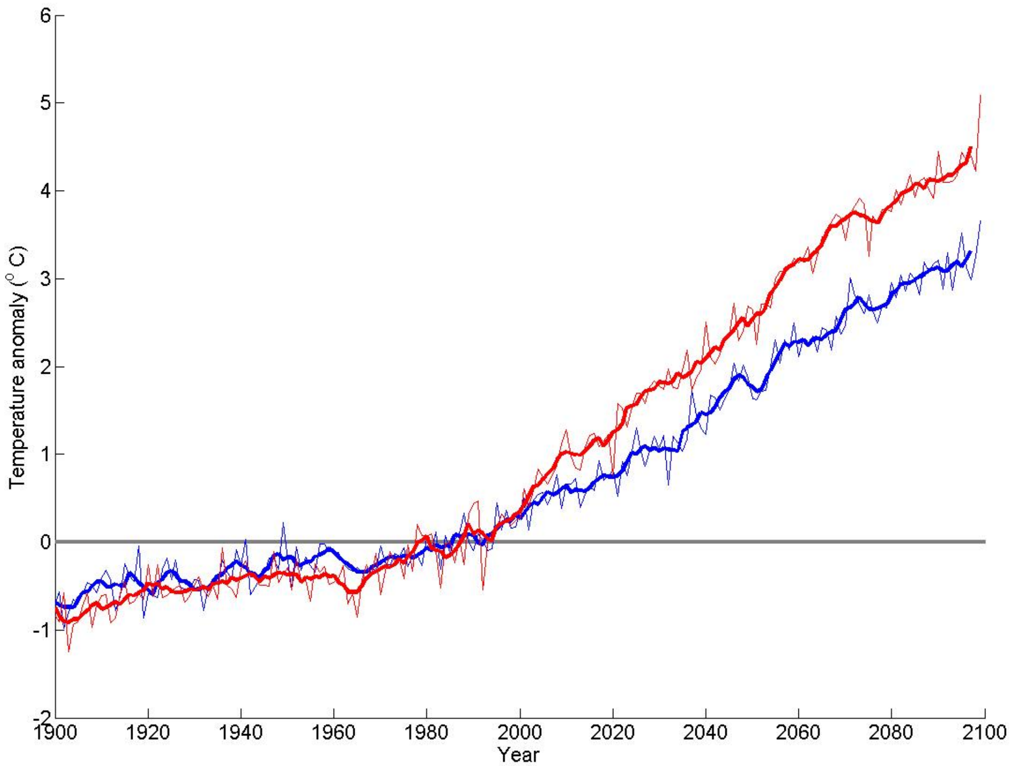


Figure II-9: New Mexico water year (October-September) annual precipitation projections compared with model climatology (1971-2000).

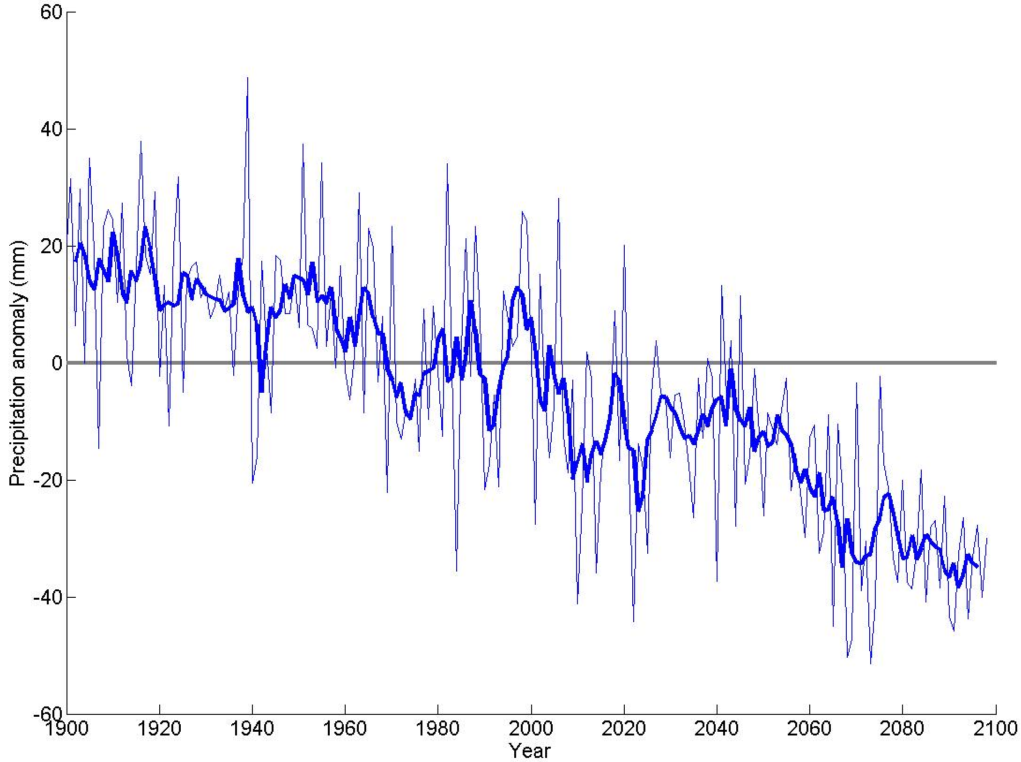


Figure II-10: Simulated New Mexico seasonal precipitation changes in the 21st Century for summer (top, red line; June-August) and winter (bottom, blue line; December-February), compared with model climatology (1971-2000).

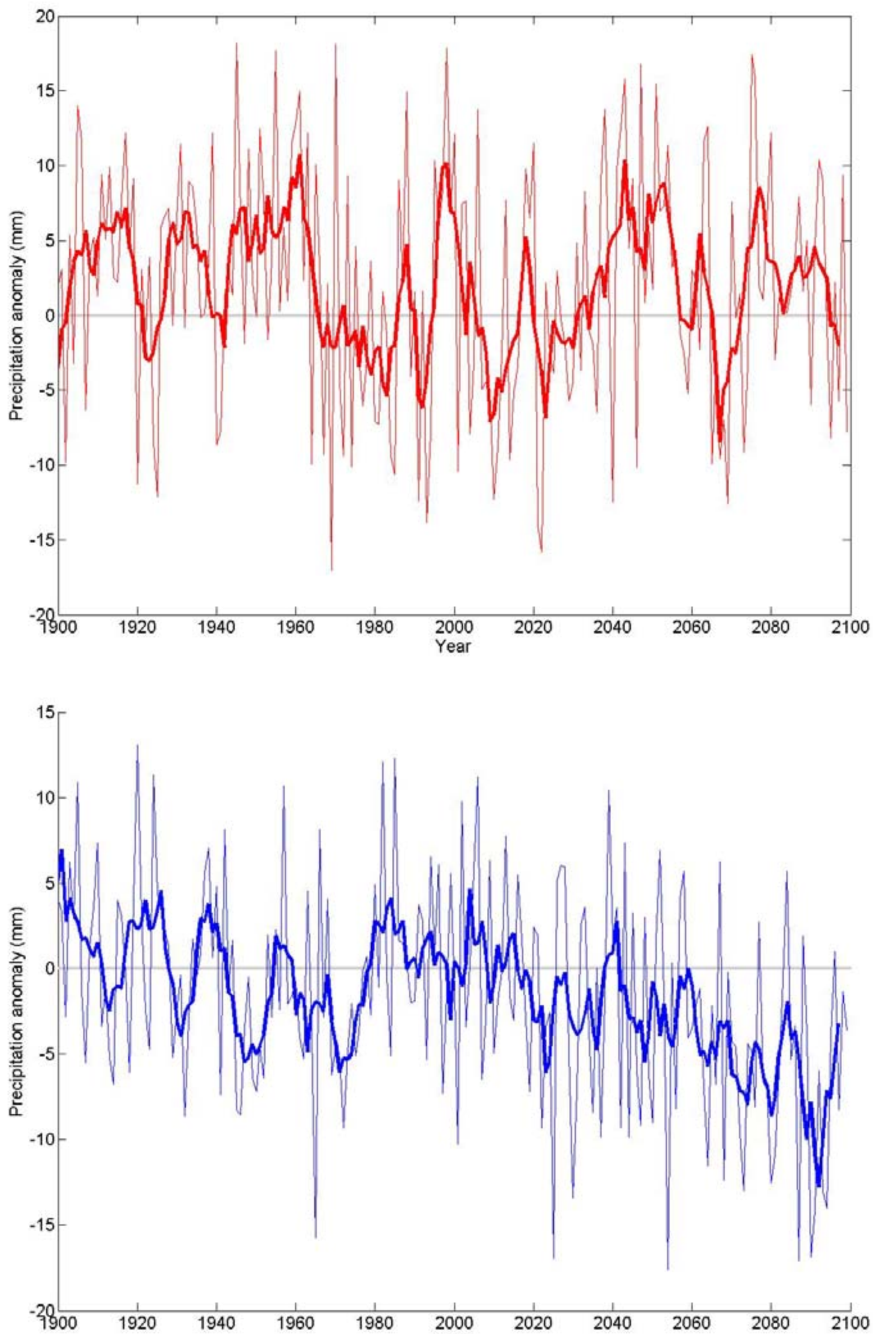


Figure II-11: Simulated change in temperature (°C) from 1961-1985 to 2071-2095 across New Mexico for (a) annual mean (b) summer (June-Aug) (c) winter (Dec-Feb). [Diffenbaugh et al., 2005]

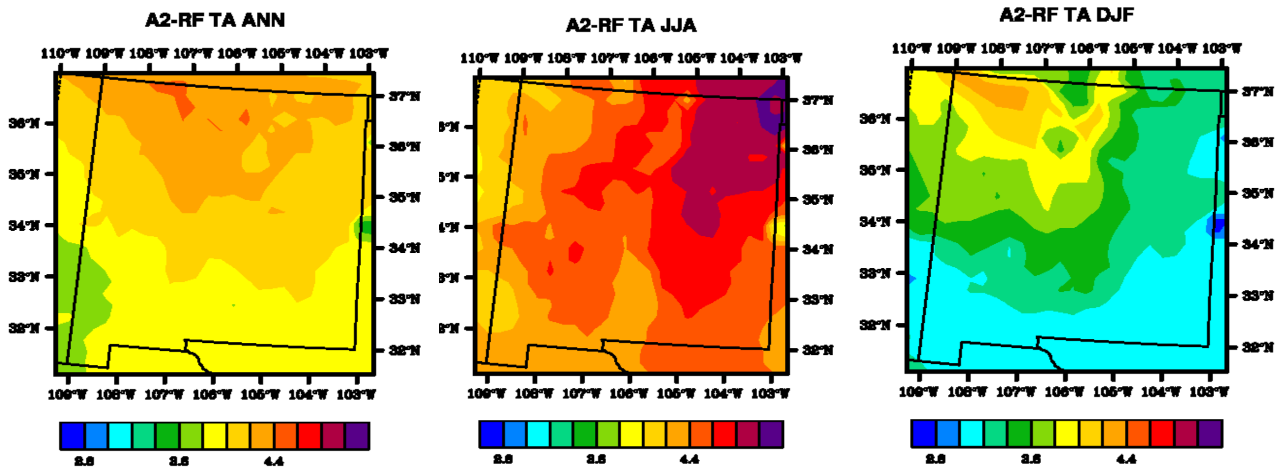


Figure II-12: Simulated change in average precipitation rate (mm/day) from 1961-1985 to 2071-2095 across New Mexico for (a) annual mean (b) summer (June-Aug) (c) winter (Dec-Feb). [Diffenbaugh et al., 2005]. Note that a change of 1 mm/day corresponds to about 14 inches of precipitation accumulated over the course of a year (panel a) and about 3.5 inches for an individual season (panels b and c)

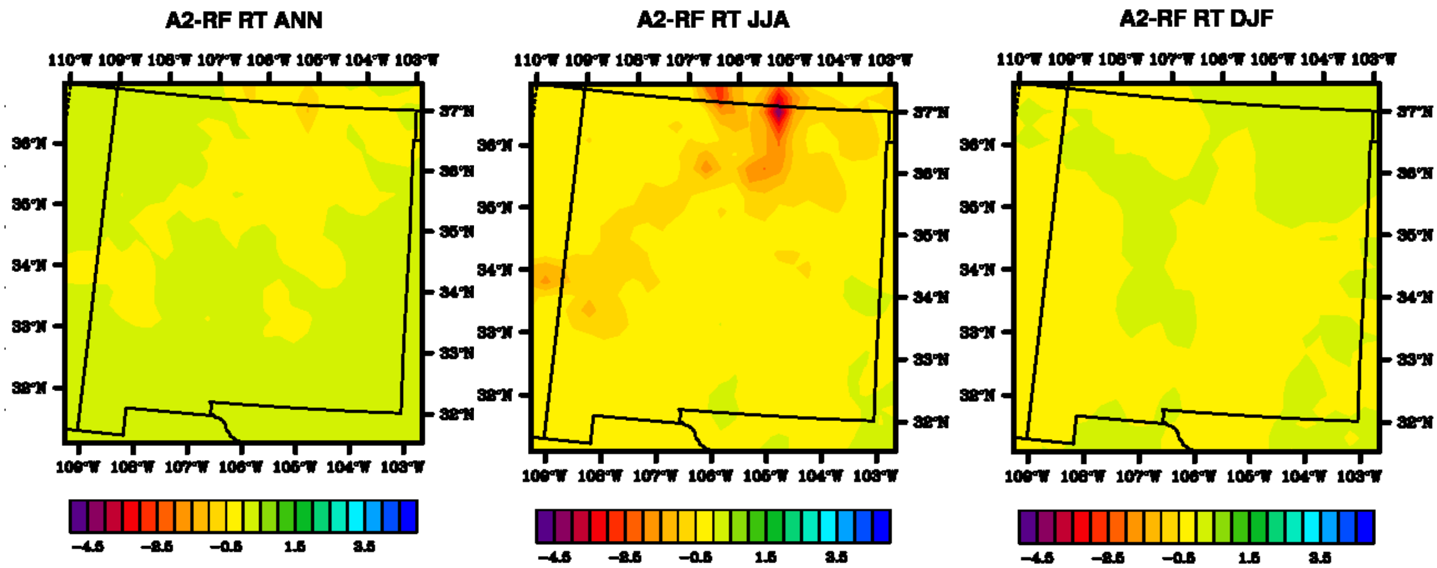


Figure II-13: Simulated change in average snowpack (mm water content in snow) from 1961-1985 to 2071-2095 [Diffenbaugh et al., 2005] for

(a) state of New Mexico on March 1 each year

(b) state of New Mexico on April 1 each year

(c) eastern Utah/western Colorado/southwestern Wyoming on April 1 each year.

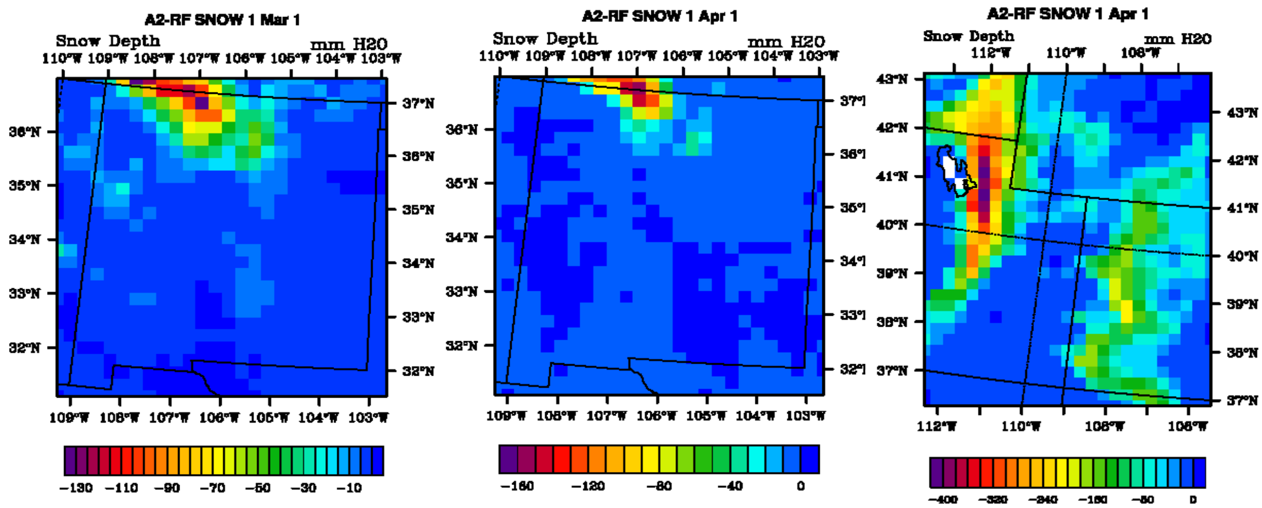


Figure II-14: Simulated change in spring season soil moisture (mm water content in soil averaged from March through May), from 1961-1985 to 2071-2095 [Diffenbaugh et al., 2005].

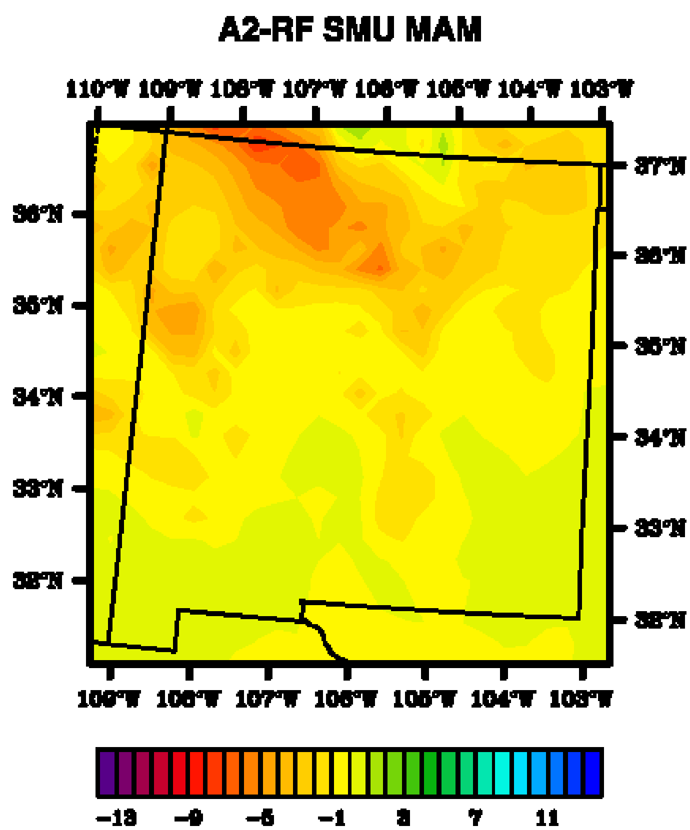
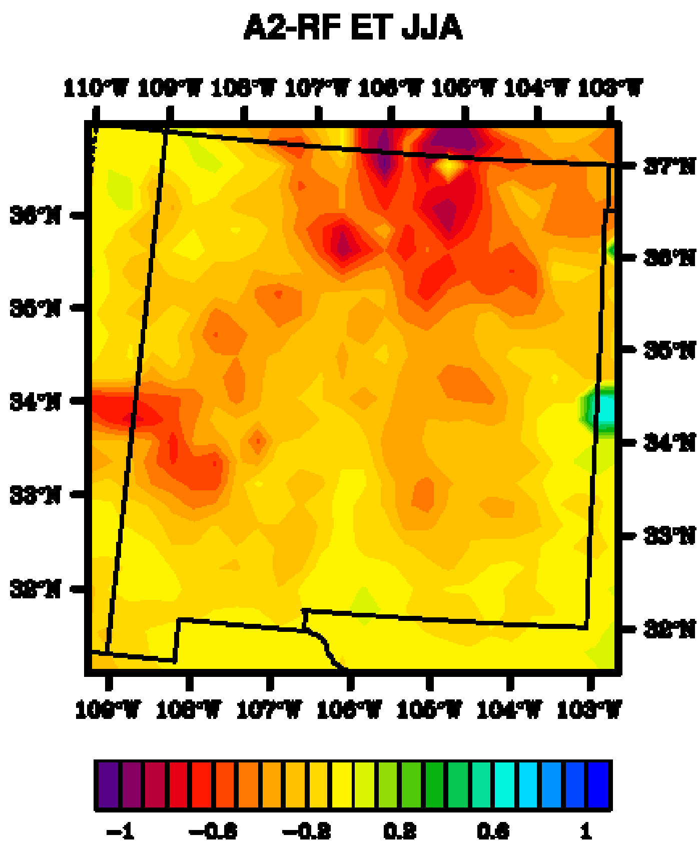


Figure II-15: Simulated change in summer season soil evapotranspiration (mm/day averaged from June through August), from 1961-1985 to 2071-2095 [Diffenbaugh et al., 2005].



III. INTEGRATING CLIMATE CHANGE INTO WATER RESOURCE MANAGEMENT

a) Introduction

Climate change has been discussed primarily at the global scale, and the primary focus of public attention and policy efforts has prudently been on the urgent need for GHG emissions reduction (mitigation) strategies. However, “recognition is increasing that the combination of continued increases in emissions and the inertia of the climate system means that …even if extreme measures could be instantly taken to curtail global emissions, the momentum of the earth’s climate is such that warming cannot be completely avoided.” [Easterling, 2004] Therefore, even if CO2 emissions were halted tomorrow, warming will likely persist throughout this century and some degree of adaptation will be necessary. While ***mitigation*** strategies are necessary to reduce the likelihood or severity of adverse conditions, ***adaptation*** strategies will be a necessary compliment to reduce the severity of potential impacts.

b) Climate change and water planning

Climate change has historically had difficulty getting on the agenda of many public and private institutions. The challenge of uncertainty (addressed below) with the resulting difficulty in assessing vulnerabilities, and the limited research and modeling available at the regional or watershed scale, has also been a disincentive. [Climate Impacts Group, 2005] Down-scaling techniques are improving the specificity and accuracy of smaller scale impacts and should support planning at the local level, where the impacts will be felt most acutely and at which adaptive management strategies will need to be designed and implemented. [Hurd, 2006]

Policy makers and managers are also constantly juggling multiple issues of immediate importance and have limited time and resources to take on what appears to be a “new” issue. Climate change is often viewed as one of those issues that can be addressed later when there is more certainty about what is really happening. However, many of the adaptive strategies required to address impacts of climate change will require years to plan and implement, and delaying may increase both vulnerability and ultimately the costs of mitigating those impacts. Often the tools needed to develop adaptive capacity for climate change are the same or similar to those used in current management practices. [Gleick, 2000]

To date, only a few states and local governments in North America have begun to address the impact of climate change on water resources, primarily in the Pacific Northwest due to the predicted dramatic decrease in snowpack coupled with rising ocean levels and potential salt water intrusion. British Columbia has a comprehensive climate change plan that includes both strategies and resource allocation. [British Columbia, 2004] Seattle has a strong climate protection initiative [www.seattle.gov/environment/climate_protection], as does Portland [Palmer, 2002]. California has also taken a very aggressive approach to climate change. Its 2005 State Water Plan update addresses climate change “qualitatively,” with the stated intent to address it quantitatively in the 2010 update as well as to provide regular updates to the Governor and Legislature. [California Department of Water Resources, 2005 and 2006] While these planning efforts incorporate climate change models and assess impacts, adaptation strategies are essentially still in the developmental stage.

New Mexico’s STATE WATER PLAN (SWP) does not specifically address climate change. However, the SWP does comprehensively describe at the policy and strategy level many of the tools that will be needed to manage the State’s water resources under a variety of conditions, including those resulting from climate change. WATER 2025 also identifies the most promising tools for dealing with the challenges to western water management, many of which are similar to or will be exacerbated by climate change. [USDOI, 2005] Thus the foundation has already been laid for incorporating climate change as an additional element to the planning process.

c. The challenge of uncertainty and confidence bounds

“Prediction is very hard, especially when it’s about the future.”
Yogi Bera

Climate change is impossible to predict with certainty, as is the weather or severity or durations of drought. “Climate varies for multiple reasons, all operating at once, many of which we do not understand well, some of which we may only suspect, and others that we simply don’t know…[which have] to be disentangled all at once from a relatively short record of 50 years of good three-dimensional observations and a little over a century of surface observations.” [Redmond, 2002] Climate is based on land and atmospheric interactions that create a chaotic system, where feedbacks are highly variable and the processes that affect the system at times behave in a non-linear manner. Uncertainties arise from attempts to predict exactly what climate changes will occur in various local areas of the Earth, and what the effects of clouds will be in determining the rate at which the mean temperature will increase. [CaEPA, 2006] “Paradoxically, to understand the driest climates in North America…we cannot fully understand the climate of the Southwest, and how and why it varies, unless we understand the climate of the entire world.” [Redmond, 2002]

Tree ring data also indicates that the Southwest has in the past experienced climate swings, including long- term severe drought. [Redmond, 2002] “Future unexpected, large and rapid climate system changes (as have occurred in the past) are, by their nature, difficult to predict. This implies that future climate changes may also involve ‘surprises’. In particular, these arise from the non-linear, chaotic nature of the climate system...” [IPCC, 1995]

“Reducing uncertainty in climate projections also requires a better understanding of the non-linear processes which give rise to thresholds that are present in the climate system. Observations, palaeoclimatic data, and models suggest that such thresholds exist and that transitions have occurred in the past … Our knowledge about the processes, and feedback mechanisms determining them, must be significantly improved in order to extract early signs of such changes from model simulations and observations.” [IPCC, 2001]

Uncertainty is inherent to the climate system and cannot be eliminated. However, delaying until all uncertainties are resolved is not viable because some uncertainties will always remain. For example, the degree of impact greenhouse emissions will have on future climatic conditions depends on future decisions and actions by governments and individuals.

“When uncertainty precludes conventional scientific analysis, yet quantitative estimates are needed for use in analysis, it is sometimes possible to obtain the judgments of experts in the form of probability distributions.” [NRC, 1999]

---*Quantitative* assessments of confidence levels [Figure I.1] are representations of researchers’ degree of belief in the validity of conclusions, based on collective judgment, observational evidence, modeling results, and theory examined [Gleick, 2000].

---In providing *qualitative* assessments on the state of knowledge, researchers evaluate the level of scientific understanding supporting a conclusion and utilize four classifications: Well-Established, Established but Incomplete, Competing Explanations, and Speculative.

Figure I.1. Confidence Levels for Assessing the Validity of Research

Very High	95% or greater
High	67-95%
Medium	33-67%
Low	5-33%
Very Low	5% or less

Source: Gleick, 2000.

These quantitative and qualitative assessments of confidence levels can be incorporated by users depending on the specifics of each decision making situation. [Hartmann et. al, 2003] While this environment of uncertainty is complex, climate scenarios developed from modeling are the best available scientific information about the probable effects of global warming. These tools, coupled with confidence assessments, provide information to support water resource managers and policy makers in the decision making process.

The uncertainty acknowledged by modelers and researchers when projecting climate change includes difficulties in forecasting forcing scenarios, modeled responses to forcing scenarios, and uncertainty caused from missing or misrepresented physical processes in models. Research has shown that better prediction information is developed through feedback between predictions and experience rather than from introducing more sophisticated predictive methods [NRC, 1999]. The processes involved will be iterative, where modelers provide information to decision makers, feedback assessments on the effectiveness of decisions will be provided to both the decision makers and modelers by water managers. It is through adaptive adjustments during this interchange that water managers can document improvements and provide decision makers and researchers with better information.

d) Risk management

The every day decisions made by water managers are based on conscious or unconscious risk assessment, where risk is defined in terms of the probability of a particular climatic outcome multiplied by the consequences of that outcome. Consequences will not necessarily vary in direct proportion to the magnitude of climate change due to the possibility of abrupt changes. While New Mexicans are experienced in dealing with climate variability, human-induced climate change is likely to take us outside the range of previous experience and thus require new strategies to cope with emerging situations that cross over previous management thresholds. Decision-makers are regularly called upon to make decisions based on uncertainty (e.g., assumptions about population growth or economic development) with an overall goal of managing future risk from a variety of different factors. Given the scientific uncertainties about the magnitude, timing, rate and local/regional consequences of climate change, water managers will need to determine appropriate responses within a framework that allows for adaptation to new data and changing conditions. [USCRS, 2006]

Climate forecasting raises ethical and legal issues for scientists that relate to risk management. Ethical questions can relate to when and how to issue forecasts, how to deal appropriately with uncertainty, how forecast skills should be developed to achieve an appropriate distribution of benefits, and how ethical beliefs (e.g, concerning the rights of nonhuman species or equity among human populations) do and should affect the development, presentation, and dissemination of forecast information. Legal research questions include assessing case law regarding responsibility for climate, weather, and analogous forecasts as well as the treatment of scientific uncertainty in the legal system, the relationship between impacts and liability settlements, and the role of legal institutions (e.g. water and property rights) in coping with climatic variability and climate forecasts [Stern,1999]

With respect to the onset of global climate change, two schools of thought have emerged regarding the adaptive capacity of water resources and water systems. The first believes that water managers already have the necessary tools to cope with climatic change and argue that key responses to climate change are virtually the same as to existing variability: that is, to upgrade supply-side and demand-side measures and add flexibility to institutions to better cope with social and environmental changes. [Schilling and Stakhiv, 1998]

The other school, however, attaches greater significance to the changing fundamentals being introduced to the climate system. A shift in the climate ‘paradigm’ increases the uncertainty. No longer can the historical record be relied upon to guide the design, construction, and planning of water projects. This school has less confidence that sufficient time and information will be available prior to the onset of significant or irreversible impacts. Proponents of this view argue that “complacency on the part of water managers may lead to the failure to anticipate impacts that could be mitigated or prevented by actions taken now.” [Gleick, 2000]

Policy and managerial responses need not (and should not) wait for better climate predictions. It is already clear that temperatures are rising and that extreme events are becoming more common, so assessing the vulnerabilities of existing management strategies and resource availability given those impacts can proceed without certainty about changes in precipitation. A close look at risk, even without firm quantification, can often lead to optimal solutions that may not be immediately apparent and that may avoid expensive missteps. [Orange County, 2004] Water resource managers already operate within a context of uncertainty about economics, demographics, water supply availability, and other conditions. Climate change is thus not a stand alone issue. It will add an additional layer of uncertainty to the complexity of water resource management in addition to population growth, land use, economic development, species protection, ecosystem demands, and other “change drivers” including peak oil. Managers will thus need robust and resilient planning scenarios and processes, and highly adaptive management structures, to adapt to changing predictions. [Hurd, 2006]

e. Adaptive management

Adaptive management strategies are appropriate to consider across the range of sectors potentially affected by changes in water resource conditions. Furthermore, these strategies can take different forms depending on the degree to which they either take a ‘wait and see,’ reactive stance or an anticipatory perspective in which potential future conditions are taken into account in system planning and design.

In considering the nature and extent of possible climatic changes, reacting to changed conditions can be ultimately more costly than making forward-looking responses that anticipate likely future conditions and events. This is an important consideration, especially with respect to long-lived assets, infrastructure, and institutions such as bridges and dams, settlement and development in water-stressed regions, interstate compacts, urban water reuse and recycling capacity etc., which may be subject to catastrophic consequences as a result of inadequate consideration in design and planning. Such a reactive, “wait-and-see” approach would be particularly unsuccessful in coping with:

- Long-lived investments and infrastructure that may be costly or prohibitive to change in response to climate change;
- Irreversible impacts, such as species extinction or unrecoverable ecosystem changes; and

- Unacceptably high costs and damages, for example, inappropriate development that exposes lives and property to intense weather or drought events. [Smith, 1997]

Proactive adaptation, unlike reactive adaptation, is forward-looking and takes into account the inherent uncertainties associated with anticipating change. Successful proactive adaptation strategies are designed to be flexible and effective under a wide variety of potential climate conditions, to be economically justifiable (i.e., benefits exceed costs), and to increase adaptive capacity (that is how and how well a system adjusts to realized or anticipated environmental changes).   [Hurd, 2006]

IV. TOOLS, POLICIES, AND STRATEGIES FOR ADAPTING WATER MANAGEMENT TO CLIMATE CHANGE.

Most of the strategies, tools and policy responses for managing water resources during climate change are not novel to this issue and have probably already been identified. Generally, responses are needed that will increase management flexibility, develop new supplies, reduce demand, and reallocate water. Accomplishing these goals implicates a variety of strategies and actions including engineering/ technology improvements, coordination among water purveyors, legal and pricing reforms, and robust demand management, to list a few. The incorporation of climate change into the State's planning for water resource management will require new modeling and scenarios, and may lead to changing priorities and revised timelines, especially the accelerated implementation of "no regrets" strategies and possible changes to statutory and institutional structures that will also ameliorate other pressures on the State's water resources.

The discussion in the literature about adaptation strategies is still quite limited, but the emerging literature suggests that there is a clear and defined role for public policy interventions to reduce vulnerabilities and protect natural resources. [Tompkins and Adger, 2005] Throughout the discussions of climate change impacts and potential responses, there are a variety of recommendations for incorporating climate change into strategic planning and for developing adaptive management strategies. Comments at various climate change conferences revolve around the need to take a comprehensive approach and to create multiple planning and adaptation strategies: while there is clearly no silver bullet, there may be "silver buckshot"!

Mainstreaming climate change vulnerabilities and adaptation strategies into water management, disaster preparedness, emergency planning, land use and development planning, and institutional/organizational design will be necessary to integrate climate change adaptation into comprehensive planning for sustainable development. [Agarwala, 2005; Burton and van Aalst, 1999] This section will provide a cursory and by no means complete discussion of some of the strategies and tools for addressing climate change, and will hopefully provide a starting point for discussion of New Mexico's options for incorporating climate change into its water planning and management agenda.

1. Strategic planning

The Western Governor's Association, on the recommendation of the Western States Water Council, recently adopted a set of policy recommendations for addressing climate change and other water issues. [WGA, 2006] The general recommendation suggested that, while recognizing the uncertainties inherent in climate prediction, western states and water managers should expand water-related plans to include climate change scenarios and should coordinate with local governments and water purveyors in developing responses.

Lester Snow, Director of the California Department of Water Resources, described this new approach to state water planning in his comments upon the release of California's Water Plan Update 2005, which addressed climate change qualitatively with plans for improved quantitative analysis over the next several years: "This …represents a fundamental change in the way state government needs to be involved with local entities and interest groups to deal with water issues in the state. The way we manage California's water resources is changing. We need to consider a broader range of resource management issues, competing water demands, new approaches to water supply reliability, and … to develop regional water plans that are more integrated…to ensure sustainable water uses and reliable water supplies in the face of uncertainty and change." [WSWC, 2005]

The ability to manage through the uncertainty of climate change will depend on good planning based on good data and modeling scenarios, and on utilizing and expanding the large portfolio of tools and systems in place that allow for robust and easily adaptable management. [Easterling, 2004] Identifying ***vulnerabilities*** to water supplies, clearly articulating the causes of those vulnerabilities, determining how climate variability and extremes might exacerbate those vulnerabilities, and establishing an analytic framework to identify the best options to correct those vulnerabilities should become part of state, regional and watershed-level water management plans.

a. Integrate predictions into planning to generate multiple future scenarios for risk analysis, both probability and consequence.

Current modeling, coupled with observed changes over the past decade, provides substantial certainty about temperature increases. While predictions about precipitation cannot be made with the same certainty, it does appear that there will be changes in precipitation patterns due to temperature increases, along with continued high persistence of variability. (See Section II for more detail on predictions for New Mexico.) This will result in changes to the hydrologic cycle (such as increased elevations for snowfall, with resulting decreased snowpack and changes to runoff patterns) which, though not yet specifically predictable, should be incorporated into management planning.

It is critically important to bridge the gap between scientists, policy makers, and water managers so that new climate change model results can be incorporated quickly into both policy and management options. The science and research community will need to prepare assessment and synthesis products to support informed discussion and decision-making about climate variability and change. Improving predictions is likely to depend not only on more sophisticated predictive methods but also on feedback, so that processes are iterative and modelers can improve their ability to provide usable and useful data and results to policymakers and water managers. [NRC, 1999]

b. Increase federal and state water data gathering activities to serve as the basis for sound decision-making.

To fully understand Southwest climate variations, a more dense network for systematic observation is necessary to identify the smaller scale effect of differences between mountains and adjoining valleys which govern the origin of most streamflow. Supporting expansion of federal data gathering programs, including the National Integrated Drought Information System (NIDIS) [www.nws.noaa.gov/ost/climate/NIDIS] as well as improving state water resource databases is prerequisite to sound decision-making. [Redmond, 2002; WGA 2006]

In addition, inadequate data is available about water availability at national, regional and local levels. "National water availability and use has not been comprehensively assessed in 25 years" according to a U.S.G.A.O. report in 2003. [Whitney, 2006] New Mexico has substantial water usage and demand data that was developed for the state and regional plans, but there are considerable gaps in knowledge about the State's water resources (especially aquifers).

c. Increase transdisciplinary and collaborative stakeholder involvement in strategic planning.

A common element of many water supply challenges facing New Mexico are the conflicting needs of people, cities, agriculture, and the environment. Success will always require a collaborative effort among stakeholders, based on recognition of the rights and interests of stakeholders, to maximize the opportunity for innovation and creativity. [USDOI, 2005] The SWP already calls for interagency collaboration and substantial public involvement, to which could be added a public education component that interjects climate change into the discussion about state water policy.

In addition, enhancing ongoing collaboration between state water managers, scientists, federal agencies, universities, and others will insure that the science of climate change is fully understood and incorporated into planning. Conversely, an improved dialogue between scientists and water managers and users is critical to scientists' understanding of data and research needs and to water managers ability to provide feedback loops to scientists to improve predictive capabilities and response analysis. [NRC, 1999]

d. Improve integrated regional water planning.

The integrated regional water planning (IRWP) paradigm calls for involvement of “myriad water users, purveyors, agencies, governments, organizations and universities to integrate diverse water-related programs that include watershed management, agricultural and urban water conservation, ground water recharge, dam rehabilitation, land use planning, water importation, reuse and recycling, desalination of brackish water supplies, and system interties.” [WSWC, 2005] New Mexico has already taken several steps in this direction:

---16 regional water plans are either completed or nearing completion, and efforts to integrate these plans into the SWP are underway;

---the FOREST AND WATERSHED HEALTH PLAN and the NON-NATIVE PHREATOPHYTE/WATERSHED STRATEGIC PLAN together form the basis of an integrated approach to watershed management;

---a water and waste water system collaboration initiative has generated substantial interest in regionalization of those systems, and the Technical Team created to support this initiative has begun to address land use and watershed management and source protection issues.

The overall objective of IRWP is to address issues that individual entities cannot resolve; promote cost effective solutions; leverage investments in existing infrastructure; integrate water management with land use, energy and other resource management issues; and address drought and flooding which are expected to result from climate change. [British Columbia, 2004] Water planning thus needs to become part of a total resource management approach. [World Conservation Union, no date]

2. Implement highly adaptive management capacity at the watershed scale

Using climate change science, despite its inherent uncertainties, will require that water planning incorporate vulnerability assessments and utilize an approach that builds increasing resiliency to climatic extremes. States will need to maintain multiple water-related plans, including not only state water plans, drought plans, reservoir management plans, flood plans, and the like, but also forest management, energy, and economic development plans which include water-related concerns. States will also need to coordinate more closely with local governments and water purveyors, which are playing an increasingly important role in water management through land use policies, development of new water supplies, water transfers, and implementation of demand management and water use efficiency programs. [WGA, 2006] This will create increasingly complex planning environments involving multiple stakeholders to enhance ways to manage all water supplies, including groundwater, surface water, and effluent, in a sustainable manner.

Watershed-scale management, such as the State Engineer is implementing through Active Water Resource Management (AWRM), is assuming increasing importance, and devising watershed management plans can not only secure sustainable clean water but also help resolve conflicts during both drought and floods. [British Columbia, 2004] Managing at this scale is also important for resolving the demand for water to support critical ecosystem services. [Whitney, 2006]

Given the importance of agriculture to the State's economy, ecology and heritage, special attention will be required to address the challenge of climate change to the State's rangelands and farming. Similarly, the implications of climate change are more threatening for natural systems, particularly aquatic ecosystems, because it will be difficult for many species to change behavior or migrate, decreasing resiliency and potential for successful adaptation. [Easterling, 2004]

Rangelands: Rangelands are an important part of New Mexico's ecology, economy and heritage, occupying over two-thirds of the surface area of the state with grasslands, shrublands, and savannas. Ranching is nearly $1 billion industry in the State. [USEPA, 1998] New Mexico's rangelands are managed by a wide variety of people and institutions with many and varied objectives. While livestock grazing currently dominates the decision making on most rangelands, they also perform other valuable ecosystem services such as climate regulation, wildlife habitat, open space, and energy production infrastructure. It is uncommon for any rangeland to be managed for only one use. Rangelands also cover much of New Mexico's watersheds, and can enhance or detract from efficient hydrologic cycle functioning and therefore affect both water supply and quality.

In general, predictions about climate change in the Southwest focus on three major changes over the next several decades: increased temperatures, shifts from summer to winter precipitation, and increased variability in both temperature and precipitation within and across seasons [IPCC, 2001]. These changes in the existing climatic regime will alter the geographical extent, the plant composition, and the ecological processes of rangelands, requiring active management approaches for land managers to remain successful in meeting both commercial and ecosystem needs. [USEPA, 2002]

Managing the State's rangelands effectively during climate change will require an adaptive management approach at all levels that emphasizes monitoring rangeland conditions and flexibility in managerial responses. Adaptive management is a well developed and proven process that has shown positive results in both economic and ecological attributes when correctly implemented. [Easterling, 2004] The State has already created two plans that provide the direction for this new management approach: the FOREST AND WATERSHED HEALTH PLAN and the NON-NATIVE PHREATOPHYTE/ WATERSHED STRATEGIC PLAN. This is especially critical given the demonstrated historical linkages between atmospheric conditions and regional fire activity: increased temperatures with changing precipitation patterns are often precursors to increased regional fire activity, which will place additional stress on water resources. [USGCRP, 2000]

Evaluating the complete range of ecosystem services derived from rangeland management, both public and private, is an important requirement for adaptive watershed management. In addition to the services already mentioned above, it is important to note that increasing temperatures and drought will present challenges to rangeland health. These include likely shifts of plant dominance and structure that are not easily reversed and often result in an increase in invasives as ecological conditions change, as well as the potential for rangeland degradation leading to an increase in blowing dust, detrimental to health and problematic for the State's highway drivers. [USGCRP, 2000] Devising strategies, tactics and operations that will best maintain a full range of services may require such tactics as redirecting conservation program incentives to support and maintain ecosystem services that provide public interest benefits at the expense of short-term economic performance. Those currently managing rangelands and/or deriving their livelihood therefrom will need to be involved early and consistently in discussions about maintaining and improving rangeland health during climate change, and additional resources will likely be required to support the management approaches required to enhance the ecological functioning of these lands. [Brown, 2006]

Farming: Crop production in New Mexico is a $500 million industry. A warmer climate, with less snowfall, more winter rain, and an earlier spring runoff could mean decreased ability to store water for use later in the summer when demand peaks, as well as increased evaporation. Farmed acres in the State could decrease as much as 25% due to these pressures. [USEPA, 1998]

Agricultural systems are managed, so farmers have multiple adaptation options including revised plant/harvest schedules, crop rotations or changes, and different tillage practices. However, agricultural systems display high sensitivity to extreme climatic events (floods, wind storms, drought) and to seasonal variability (frost dates, rainfall patterns). Increased rainfall intensity can increase soil erosion, along with degraded water quality from increased movement of agricultural chemicals and waste into water bodies. Coupled with increased temperatures, it can result in increases or changes in pests and invasive species. [Adams, 1999]

Agricultural policies will need to address both the challenges and opportunities of climate change while also adapting to other pressures. Although the role of soils and crops in carbon sequestration is not yet fully understood, it should play a role in farming techniques as well as crop selection. The opportunity for New Mexico's growers to provide feedstock for production of ethanol and biodiesel may open new markets to support changing crop patterns. [Ebinger, 2006]

Policies will also need to address the impact of the peaking of world oil production, which will result in higher oil prices and a liquid fuels problem for the transportation sector. [Hirsch, 2005] The agricultural sector is heavily dependent upon diesel fuel: for transportation of fertilizers and pesticides (most of which are produced from petroleum), and for transportation of products to markets. U.S. consumers are also heavily dependent upon petroleum for transportation of food. The combined challenge of "peak oil" and food production has increased interest in the development of local food production and urban agriculture, and calls for careful evaluation of pressures to move agricultural water to other uses.

Aquatic ecosystems: Aquatic and wetland ecosystems display high vulnerability to climate change. Changes in water temperature and shifts in timing of runoff will change aquatic habitats, resulting in species loss or migration as well as novel and unpredictable interactions of new combinations of species. [Fish, 2005] Stream management practices will have to accommodate these new threats to aquatic species, increasing Endangered Species Act (ESA) and threatened species challenges. [Poff et. Al, 2002]

3. Infrastructure and technology options

The SWP includes a policy and strategies for improving the use of and for enhancing water supplies through continued improvements in technology. Many western universities, as well as the national laboratories, have research programs that could be focused on practical applications of new and existing technologies to improve water management and expand water supply. [WGA, 2006] Climate change will add an additional pressure to the other variables that already challenge water managers dealing with aging infrastructure and distribution demands.

There are three major areas in which science and technology should play a major role in addressing this and other U.S. water challenges [Whitney, 2006]:

a. Improving use of existing infrastructure: Increased application of management systems (such as Supervisory Control and Data Acquisition, or SCADA; meter telemetry) will improve the efficiency of infrastructure management, in addition to providing the feedback loops and quick response time required for adaptive management.

b. Expanding supply through new technologies for water reuse, desalination, weather modification and expanded use of lower quality water: Implementation of new technologies may require regionalization in order to achieve the scale necessary to justify investments, and additional research will be necessary to determine effectiveness and feasibility (for weather modification, for example). A comprehensive study of untapped but impaired water supplies in the State could focus development in those locations with a high probability of water demands exceeding supplies, as well as those most likely impacted by climate change. [U.S.D.O.I., 2005] Costs for many of these are decreasing, while experience from implementing new technologies is providing direction for more efficient and effective use in the future. NOTE, however, that both increasing energy costs and the need to decrease greenhouse gas emissions are major considerations in determining an appropriate role for these new technologies. (see Part 4 below)

c. Developing new approaches to water storage: New Mexico already loses a substantial amount of water through evaporation. Improving both surface and groundwater storage alternatives, including aquifer storage and recovery, are key areas for technological advancements.

Infrastructure vulnerability assessment: Safe engineering design depends upon a probability analysis of historically observed hydrologic events. One of the anticipated impacts of climate change is an increase in extreme hydrologic events, both flood and drought. [Groisman et. al., 2001] Rain has increased in the U.S. by 7% in three decades; heavy rain events of more than 2 inches a day have increased 14%, and storms dumping more than 4 inches a day have increased 20%. [Epstein, 2006] Historic records may therefore not reflect the magnitude of future events. The “return period” for hydrologic events is also based on the average, historically-observed elapsed time between occurrences of different magnitudes, and this may also change significantly with climate change. Assuring that existing infrastructure will withstand both more extreme and greater frequency events will require vulnerability analysis and possibly cautionary retrofit. Engineering manuals that provide design standards for hydrologic analytical methodologies will need to be revisited and revised to insure that anticipated changes in the magnitude of hydrologic events are incorporated into designs for new infrastructure. [Hernandez, 2006]

Reservoir management: Warming and loss of snowpack will impact operations of many of the state's reservoirs. More precipitation as rain, coupled with the retreat of snowpacks to higher elevations, will increase reservoir inflows during the winter and early spring months, resulting in empty flood control space previously maintained during winter months being filled earlier with runoff. Especially with the potential for extreme flood events, more annual runoff is likely to go through reservoirs earlier in the year, decreasing the amount available for hydropower and irrigation uses later in the year. Reservoir managers will need to search for physical, regulatory, and operational flexibilities to accommodate these changes. [CaDWR, 2006]

4. Demand management, conservation, and efficiency

The IPCC, in each of its assessments to date, has noted that water demand management and institutional adaptation are primary components for increasing flexibility to meet the uncertainties of climate change. [IPCC 1995, 2001] Innovative water conservation practices could decrease water use, and management innovations could increase efficiency with limited environmental impact. [CaDWR, 2006] Most agricultural irrigation water delivery systems were built in the early 1900s. Lining or enclosing of canals where appropriate, rehabilitation of irrigation system infrastructure, and application of new automated and remote-controlled water management technologies using low-cost solar-powered components, while requiring significant initial investment, can modernize existing systems and improve efficiency of water delivery, often with substantial savings. [USDOI, 2005]

Most urban (i.e. non-agricultural; the term "urban" will be used for the municipal, domestic, commercial, industrial and institutional sectors) water systems were built in the middle of the last century. A combination of aging infrastructure and increasing demand is generating need for replacement or upgrading of systems, providing the opportunity not only for decreased conveyance loss but also for integrated regional water and waste water system design that can incorporate such opportunities as use of pre-treatment water for golf courses and other non-potable demands, thereby optimizing the use of and extending the existing water supply.

Urban sector: The fastest growing demand for water is the urban sector, with water supplies limited and water rights at a premium. The majority of New Mexico's drinking water systems are rural, and much of the population depends upon community water systems or domestic wells. Climate change, particularly long term drought, can result in loss of water sources, as well as a rise in turbidity and in levels of contaminants regulated by the Safe Drinking Water Act (SDWA). It will also exacerbate existing challenges, including uncertain future demand, changing demographics, unanticipated treatment costs, changing quality regulations, infrastructure maintenance and upgrades, and developing new water supply options. [Palmer and Hahn, 2002] Some of the climatic events that are most disruptive to water systems will be compounded by climate change: high temperatures and drought (which increase demand); high winds and electrical storms (that cause electrical outages); and heavy precipitation and flash floods (that may cause breakage or exposure of infrastructure, overload the capacity of waste water systems, and impact water quality and turbidity). [Carter and Morehouse, 2003]

Confronting the additional pressure of climate change with existing challenges is already leading to collaboration among small water systems. Regional planning and infrastructure development will need to integrate drinking water, waste water, source water protection, new supply development, and demand management for sustainability. A State water conservation plan for this sector would establish policies and strategies to decrease both domestic and commercial use, along with appropriate State programs to facilitate and accelerate implementation of practices with the greatest potential for successful reduction of water use. Such a plan should include such accepted strategies as metering; per capita usage goals; subdivision, development and construction code changes to encourage water efficiency and grey water reuse; and land use guidelines to encourage water-efficient development landscaping. The State's "Our Communities, Our Future" initiative has developed a multi-pronged approach that includes many policies and statutory/regulatory recommendations to support sustainable water supplies. [Hughes, 2006]

Agricultural sector: Most irrigation systems are already implementing some efficiency and conservation techniques. [King,2005] Resources for such improvements could be targeted to areas where additional water is needed for environmental or other purposes. Re-evaluation of current farming technologies and cropping patterns, particularly perennial crops such as orchards, will need to be done in the context of climate change to assist farmers with appropriate adaptations.

Water/Energy nexus: "Water and energy are interdependent," according to Mike Hightower of Sandia National Laboratories. Much of energy production requires water, and water pumping and treatment require a lot of energy. [WSWC, 2006] Increased demand for energy (for cooling, anticipated with temperature increases) leads to increased demand for water that is unlikely to be offset by decreases to winter demand (from reduced heating). [Smith and Tirpak, 1989; Sailor and Pavolova, 2003] Increased demand for potable water leads to increased demand for energy.

Providing water for multiple purposes is also energy-intensive. The California Energy Commission estimates that providing water to the State results in an average of 44 million tons of carbon dioxide emissions. End uses of water, including heating for domestic, commercial and industrial operations, also consume energy, as does waste water treatment. Consequently, any reductions in energy consumption related to water will decrease GGEs. [CaDWR, 2006]

There is thus a strong link between energy and water conservation, with opportunities to achieve both through collaboratively planned projects. Including energy savings can improve the economic justification for water conservation projects and may be one of the best ways to reduce energy use and therefore emissions. Water conservation can lower energy use and energy bills. Water recycling is a highly energy efficient water source. Both water and energy policymakers should give water conservation higher priority as a mutual benefit. [Cohen et. al, 2004]

5. Statutory, regulatory and institutional barriers.

"States should evaluate and revise as necessary the legal framework for water management to the extent allowable to ensure sufficient flexibility exists to anticipate and respond to climate change." [WGA, 2006] WATER 2025 also identified that water management could be improved through removal of institutional barriers. [USDOI, 2005] An extensive literature on the important role of institutional capital to plan, facilitate, implement, monitor, and sustain adaptations to climate change has noted that appropriate institutional mechanisms may be absent and that long-lived institutions may be unable to accommodate the restructuring necessitated by adaptations. [Young, 2002; Easterling, 2004] In the Colorado River Basin, for example, measurements of the economic effects of hypothetical changes in climate and precipitation indicate that much of the total damages result from the current inflexibility of the Colorado River Compact. [Loomis et.al., 2003] The Endangered Species Act (ESA) and the National Environmental Policy Act (NEPA) may limit habitat management options; river restoration and species protection may not be compatible or synergistic; and managing aquatic ecosystems in arid lands with climate uncertainties may be compromised. [Cowley and Sallenave, 2006] Water policies, including pricing and inadequate quantification of water rights as well as related issues such as land use, can inhibit conservation and limit valuable flexibility in market-oriented transfers. [Easterling, 2004]

While certain to send a shudder through water attorneys, managers, and multiple stakeholders, pressures on water resources (drought, increased demand, changing regulatory requirements, sustainable development) have already highlighted areas where new approaches are required. Climate change will add to that pressure and call for re-evaluation of existing structures.

6. Sustainable development.

Sustainability is often defined as "meeting the needs of the present without compromising the ability of future generations to meet their own needs." Sustainable development involves a comprehensive integration of economic, social and environmental goals that will need to incorporate the impacts of climate change. [Robinson et.al, 2006] Climate change will add an additional pressure, and an unpredictable variable, to those already faced by New Mexico in meeting its water needs. However, climate change and sustainable development policies can reinforce each other; for example, the reduction of non-renewable energy consumption and conservation practices that also reduce greenhouse gas emissions. [Swart, 2003]

While the published literature on the impacts of climate change is substantial, that on the links to sustainability is still scarce. That on adaptation strategies is also limited, other than general descriptions of options and opportunities briefly described in this report. However, much of the response to climate change will necessarily be local, because that is where the impacts will be felt. [Easterling, 2004]

V. CONCLUSION

"I have found that plans are useless, but that planning is priceless."
President Dwight Eisenhower

New Mexico's water future will be determined by water demand and availability of our water resources. Climate change will likely have a significant affect on both. Continued and exacerbated variability, coupled with changes in amount, form (rain vs. snow), location, and intensity/duration of precipitation events are anticipated results of climate change, and these changes will have serious consequences for water managers. [Smith, 2006]

There is a clear and defined role for public policy intervention in adapting to climate change. [Tompkins and Adgar, 2005] The key to successful adaptation is a robust scenario-based planning structure. The STATE WATER PLAN provides a policy framework to which climate change can be added as an additional pressure, albeit perhaps a potentially more dangerous one. It and the State's regional plans already include many of the strategies required to address climate change. Identifying likely changes and quantifying the range of potential impacts will allow the State to identify and evaluate adaptation options, and to compare costs and benefits against both "no action" risks as well as strategies already in place to meet additional demands. It will set the stage for moving forward with those "no regrets" strategies that clearly address both climate change and other challenges, while continuing to investigate other pathways that may be less clear.

Building the adaptive capacity required to manage climate impacts before they occur is the ultimate objective of such planning. Building such capacity will evolve over time as new modeling results become available and additional defendable adaptation opportunities become evident. Water resource planners and managers will need to incorporate monitoring, re-evaluation and adjustment of policies and strategies into management activities to respond to climate changes and additional pressures and demands. Doing so will better position water resource managers to meet objectives that might otherwise be compromised by changing climate conditions. [Climate Impacts Group, 2005]

Adaptation is not likely to be a smooth process or free of costs, and it is by definition on-going rather than a one-time solution. [Easterling, 2004] Planning need not and should not wait for "perfect" climate predictions on precipitation---action can be initiated now based on what is known: that temperatures are increasing with resulting changes in precipitation and that extreme events are likely to become more common.

Given the latest scientific research on the impacts of climate change, it appears that there would be some urgency as well as substantial benefits from stoking New Mexico's adaptive capacity with proactive policies and strategies in anticipation of what is likely to come. As Governor Bill Richardson said on February 28, 2006, when announcing the Arizona/New Mexico collaboration on the Southwest Climate Change Initiative, “In the Southwest, water is absolutely essential to our quality of life and our economy. Addressing climate change now, before it is too late, is the responsible thing to do to protect our water supplies for future generations.”

APPENDIX A: CLIMATE CHANGE WATER IMPACTS WORK GROUP

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